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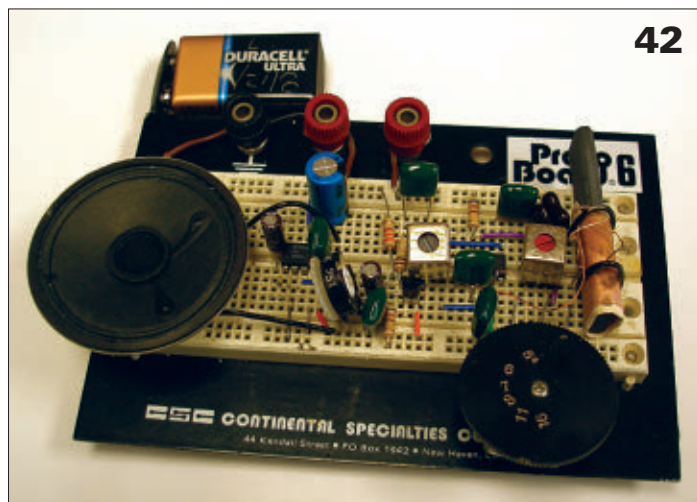
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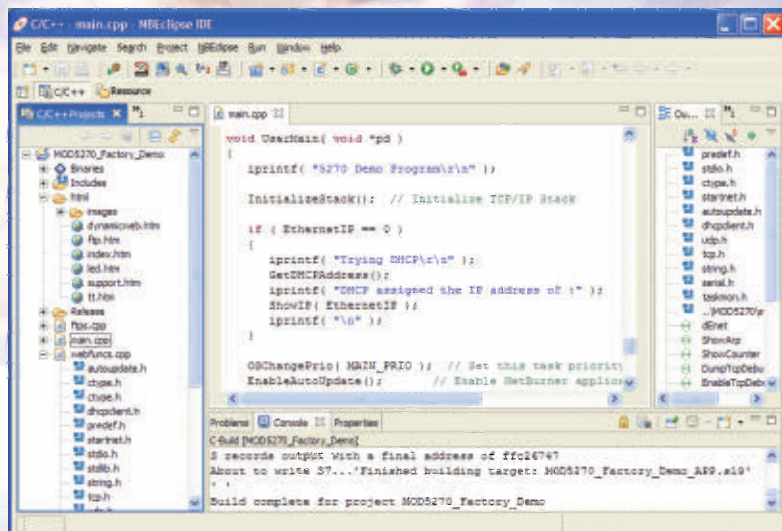
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It's in the cards ...

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noise amplifier. There's a significant price penalty, however.

This price-versus-performance issue applies to everything from connectors — gold plated versus tin-plated — to the volume control. You can go with an inexpensive carbon log potentiometer (\$1.89), an inexpensive ALPS step attenuator (\$45), or a DACT audiophile-quality step attenuator (\$189). Step attenuators — which are made with switched fixed resistors — have a nice feel and largely avoid the scratchy noise associated with a typical potentiometer. But there is the issue of diminishing returns.

Component selection is usually a compromise, even when you know what you want. You might work with an online database and catalog for hours, only to reach the end of your component shopping list to discover that a key component either isn't available or must be purchased in lots of 10, 100, or 1000. Then you search another site and find the component is available in the quantity you need. Do you start over with or incur an extra shipping charge and order from both suppliers? Or do you reconsider your design and use a component that is available from the first company?

Furthermore, how many 'spare' components should you order? If you've worked with surface-mount components, you know what I mean. An inappropriately timed blast from a hot air pencil can send a component flying across the room. Do you really want to spend an hour searching for an eight cent capacitor?

Layout

The complexity of your project may dictate a printed circuit board over a breadboard. If so, you'll have to select from among the half dozen or so board development systems and design your boards. (I like ExpressPCB for simple projects and Eagle for complex layouts.)

Back to the headphone amp example, given the design constraints, you'll have to decide whether to use a single board or the more expensive option of using a separate board for the power supply. In either case, you'll also have to determine whether to mount the power transformer on the board or directly on the chassis.

Starting Over

Circuit development is about making a series of prototypes. The endpoint is never perfection, but something close enough that you can live with it — and feel good about sharing it with others. I've been developing circuits for decades, and have learned that, despite my best efforts, a circuit is a prototype until at least version two. Sometimes it's as simple as forgetting to specify a trace-free zone around the bolt holes of a circuit board. Sometimes it's a complex ground loop problem that requires a new layout.

As you read the projects in this issue, consider the time, resources, and effort that each author has expended in sharing their designs. If you're new to the development process, start with one of these projects, and gradually work your way up to creating your own designs. Enjoy the journey. **NV**

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BETTER COMMUNICATION

I have read the Open Communication column on "How Far You Can Go?" by Mr. Frenzel; I think I have to comment on it. He presented some calculations which are apparently correct. But he failed to include the most important parameter in radio communication: the signal-to-noise ratio. Noise is only mentioned in the concluding remark, but I am afraid the noise bandwidth (corresponding to the transmitted signal spectrum) and resulting noise power is what really defines — in the S/N ratio — how far you can go.

I understand it is a superhuman effort to present the complex radio communication principles in a short article in a popular magazine.

Nevertheless, there are textbooks

on the problem, understandable to not only college graduates. The best one is the ARRL *Radio Amateur's Handbook*.

In my opinion, it would be better to refer the N&V readers to such a basic textbook for the best reference than to try to put everything important into the short article. By doing just that, W5LEF missed one of the most important points.

Recently, many digital radio systems promised high data rates achieved through an "impossible" radio environment. W5LEF mentioned only shortly that "multipath" exists. But just in those new radio data systems, the multipath is the most critical problem. Many users erroneously think that their gadgets must operate anytime and anywhere. They have to learn by trial and error what is really possible.

Unfortunately, multipath problems have not yet been discussed in popular textbooks. Radio communication often is not so easy as it might seem from the commented article.

— Jiri Polivka

Response: Thanks for your note on my article. You are certainly right about SNR. It is the core of communications. There is little you can do to control or reduce the noise, but you can do something about the signal level and that is what my article was about — how to boost the robustness and range with a greater power. That is the practical aspect of wireless these days and what I believe is what N&V readers want to know. There is just not space in a magazine to cover all aspects of wireless so we need to focus. Best wishes for 2008.

— Lou Frenzel

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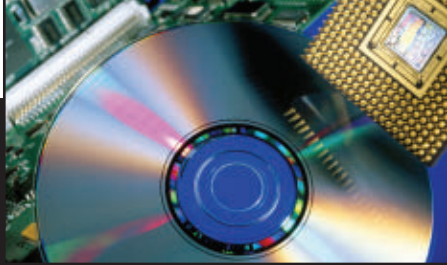
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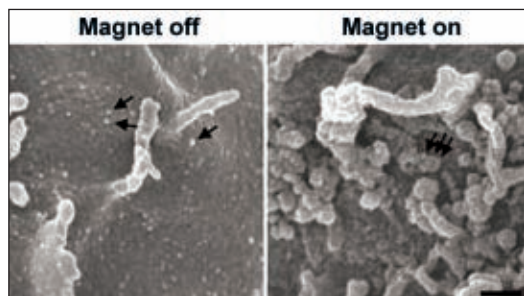
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■ BY JEFF ECKERT

ADVANCED TECHNOLOGY

MAGNETIC BEADS MAY CURE DISEASE



■ Left: Cells precoated with magnetic beads, each binding to a cell receptor. Right: Magnetic field applied, causing beads to cluster together, triggering biochemical responses.

PHOTO COURTESY OF DON INGBER, PH.D., CHILDREN'S HOSPITAL BOSTON.

Researchers at Children's Hospital Boston (www.childrenshospital.org) are developing a new type of nanobiotechnology that uses magnetism to control events at the cellular level, which could enable noninvasive treatments for a variety of diseases. In collaboration with Harvard University (www.harvard.edu) physicist Mara Prentiss, Don Ingber and Robert Mannix figured out a way to get 30 nm beads to attach themselves to receptor molecules on the surface of mast cells, which are part of the immune system and are involved in healing and defense against pathogens.

In a demonstration, the cells were subsequently exposed to a magnetic field, which stimulated an influx of calcium into them. (Apparently, calcium influx is a signal that various cells use to initiate nerve conduction, stimulate muscle contractions, or start secretion processes.) Without the magnetic fields, the beads had no effect.

What we're talking about is a 5 nm inner particle coated with antigens for a total 30 nm size. They can be magnetized and demagnetized over and over, making them all the more useful. "This

technology allows us to control the behavior of living cells through magnetic forces rather than chemicals or hormones," noted Ingber. "It may provide a new way to interface with machines or computers in the future, opening up entirely new ways of controlling drug delivery, or making detectors that have living cells as component parts. We've harnessed a biological control system, but we can control it at will, using magnetic forces."

Possible applications include controlling insulin production in diabetics, control of heart and breath rates in neonatal ICUs, and stimulation of antidote production when a toxin or infection is sensed. Stay tuned for further refinements.

BREAKTHROUGH HARNESSSES THERMO-ELECTRIC ENERGY

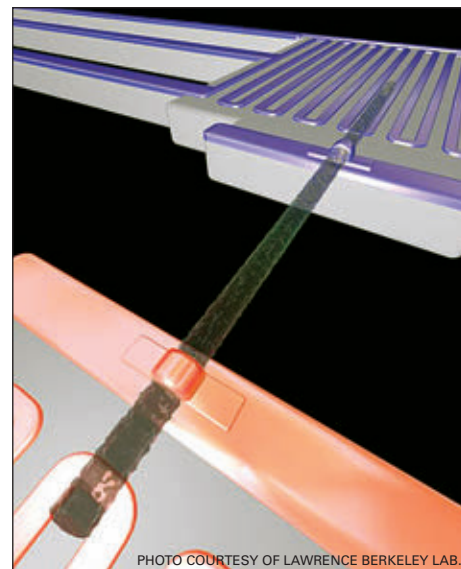
According to the US Department of Energy's Energy Information Administration (www.eia.doe.gov), the world will be sucking up more than 16 trillion kilowatt hours of electrical energy by 2010, up from about 13 trillion in 2001. Most electricity is still generated by gas or steam-powered turbines that turn heat into mechanical energy, which then is converted to electricity. The process involves enormous waste, however, as much of the heat escapes into the environment. But researchers with Lawrence Berkeley Lab (www.lbl.gov) and the University of California at Berkeley (www.berkeley.edu) have come up with a new type of thermoelectric material based on silicon nanowires that could recapture a great deal of what we're currently losing, and it can be applied to

everything from power generation plants to automotive exhaust systems to warm-up suits.

Simply put, when you heat one end of a thermoelectric wire, electrons move to the colder end and produce a current. But such materials have been too inefficient to be very useful or too expensive to be very practical. The key is to find a cheap substance that has good electrical but poor thermal conductivity, resulting in a "thermoelectric figure of merit" (ZT) of 1.0 or better.

The Berkeley team seems to have made significant progress using an electroless etching process to produce a particularly rough form of silicon nanowire that — at 50 nm dia — achieves a ZT of 0.60 at room temperature. Although the physics are not yet fully understood, it is demonstrable that the new material's rough surface is critical to its performance.

By reducing the wire diameter and improving doping and roughness, they believe that a ZT of 1.0 or better is achievable. Berkeley Lab's Technology Transfer Department is now seeking industrial partners to further develop and commercialize the technology.



■ Rough silicon nanowire connecting a heat source (bottom) to a sensor (top).

PHOTO COURTESY OF LAWRENCE BERKELEY LAB.

COMPUTERS AND NETWORKING

FASTEST MAC INTRODUCED



PHOTO COURTESY OF APPLE, INC.

■ The new Mac Pro features eight processor cores and a 3.2 GHz clock rate.

In January, Apple (www.apple.com) introduced a new version of the Mac Pro desktop, said to deliver twice the performance of its predecessor (i.e., a 2.66 GHz, quad-core machine). It uses two of Intel's 45 nm quad-core Xeon processors and features up to 3.2 GHz clock rates, a 1,600 MHz front side bus, up to 4 TB of internal storage, and as much as 32 GB of 800 MHz RAM. According to Apple, this provides the fastest Xeon architecture on the market. It also comes standard with the ATI Radeon HD 2600 XT graphics card with 256 MB of video memory.

The machine is designed to be particularly useful for film and video editing. Prices start at \$2,700 for the 2.8 GHz version with 2 GB of memory. But if your wallet is fat enough, you can get the totally tricked-out configuration with all options (including four 1 TB internal drives, dual monitors, and a printer) for only \$27,240.90. (Hint: Buy your memory somewhere else. Apple ups the ante by \$9,100 to upgrade from 4 to 32 GB.)

NEW LOW-END LAPTOP

For those of us who are more pecuniarily challenged, there is the CloudBook mini-laptop computer from Everex (www.everex.com). The

■ The new Cloud-Book ultra-mobile.

company has been shipping PCs under private labels since 1985 and specializes in products with "the lowest possible cost of ownership ... without sacrificing quality, workmanship, or service."

Having been available for about a month by the time you read this, the CloudBook is a 2 lb, 9 inch long package that features a 1.2 GHz VIA C7-M processor (from Taiwan's VIA Technologies), the Linux-based gOS operating system, 512 MB of DDR2, a 30 GB drive, and a range of applications including OpenOffice. You can pick one up online or at Wal-Mart for about \$400.

THE NEXT ANNOYANCE: CROSS-SITE PRINTING

The Internet continues to be dangerous waters for surfing, and a new pain in the posterior may invade your system soon. Aaron Weaver, a security manager in the financial industry and by all accounts a swell guy, has discovered a relatively unknown hole in most Web browsers. Apparently, a malicious website (or an innocent one that simply contains a cross-site scripting flaw) can take over your printer and generate hard-copy spam before you know what's going on. As you may have noticed, your browser can connect to the network port your printer uses to look for new print jobs.

All a hacker needs to do is send you some nasty JavaScript code to get the process started without your knowledge or permission. The good news is that this works only with networked printers, so if you use a direct connection, you're safe. The bad news is that, with a little refinement, the concept could also be used to make your printer send a fax, accept malware, or even reformat a hard drive (if it uses one). For details, you can download the CrossSitePrinting.pdf from <http://ha.ckers.org>.

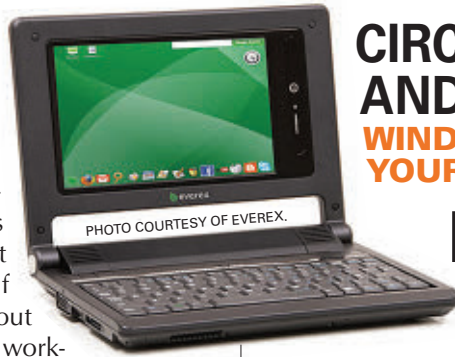


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CIRCUITS AND DEVICES

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Billed as the first fully integrated wind generator designed specifically for the grid-connected residential market, the Skystream™ 3.7 system is a new weapon in the battle against rising electricity costs. Developed by Southwest Windpower (www.windenergy.com) in collaboration with the US Department of Energy's National Renewable Energy Laboratory (www.nrel.gov), it produces electricity for a fraction of the cost of previous technologies. Interestingly, it uses no batteries; instead, it connects directly to the home wiring. You simply fix the 170 lb windmill atop a tower ranging from 33 to 110 ft (10.2 to 33.5 m), and its universal inverter provides power that is compatible with any utility grid from 110 to 240V.

If the unit generates more energy than you need at any particular time, it feeds the power back into the grid and makes your meter run backward. The catch, of course, is that you need to live in a location where there is enough wind to make it practical. The system's cut-in wind speed is 8 mph (13 kph), and the energy savings cited by the company are based on a 12 mph stream and utility charges of \$0.09/kWh. On those assumptions with a typical installation cost of \$8,000 to \$10,000, the system will provide annual savings of \$500 to \$800 per year and pay for itself in five to 10 years. But if you live in a state that offers investment rebates or has unusually high energy costs (e.g., Hawaii), you can do considerably better. The system is rated to survive wind speeds up to 140 mph (225 kph).

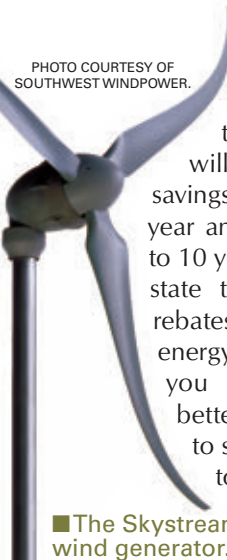


PHOTO COURTESY OF SOUTHWEST WINDPOWER.

■ The Skystream 3.7 residential wind generator.

INDUSTRY AND THE PROFESSION

50TH ANNIVERSARY OF THE IC

PHOTO COURTESY OF TEXAS INSTRUMENTS.



■ Jack Kilby with lab notebook open to first "solid circuit" drawing.

In my opinion, there are only a handful of people whose works have truly transformed the world and the way we live in it," said Texas Instruments (www.ti.com) chairman Tom Engibous. "Henry Ford, Thomas

Edison, the Wright Brothers, and Jack Kilby." With these words, we note that 2008 marks the 50th anniversary of Jack's successful use of germanium mesa p-n-p transistor slices to form transistor, capacitor, and resistor regions, thus inventing the integrated circuit. Using fine gold "flying wires," he connected them to demonstrate an oscillator function and, a week later, produced an amplifier. The following year, TI announced Jack's breakthrough "solid circuit" concept and followed it up with its first commercial offering, the Type 502 Solid Circuit Microelectronic Binary Flip-Flop. Somewhat belatedly, Kilby was awarded the Nobel Prize in Physics for his work in 2000. He passed away in 2005 but will not soon be forgotten.

and comes with a five-year warranty.

... AND FUEL CELLS FOR ANYWHERE

Millennium Cell, Inc. (www.millenniumcell.com), and Horizon Fuel Cell Technologies have jointly demonstrated a preproduction version of the HydroPak™ power generator, which incorporates Horizon's commercial grade fuel cells and hydrogen cartridges developed by Millennium. According to the latter,



■ The HydroPak portable power generator.

PHOTO COURTESY OF MILLENNIUM CELL, INC.

you just add water to a dry cartridge to draw 400W for up to 16 hours.

HydroPak is designed with a standard AC outlet, as well as twin USB connectors for charging or operating various low-power devices (e.g., lights, notebook computers, and small TVs). Production quantities of the \$400 unit are slated to be

available later this year, in time for the arrival of hurricanes and winter storms.

The disposable cartridges will run \$20 each, so HydroPak doesn't come close to a standard gasoline-driven generator in terms of cost per watt. But it is quiet and clean, and gas isn't getting any cheaper.

PLAYER COMBINES AUDIO, MOVEMENT, AND LIGHTING EFFECTS



PHOTO COURTESY OF SONY ELECTRONICS.

■ Sony's Rolly audio player, with speaker ports open.

It measures only 4 x 2.6 x 2.6 in (104 x 65 x 65 mm) and weighs just 10.6 oz (300 g), but Sony's (www.sony.com) Rolly — demonstrated at the 2008 Consumer Electronics Show (CES) — packs a lot of features into the small package. The sound quality is said to be surprisingly good, by virtue of a digital amplifier and neodymium magnets in the speakers. The bass end of the sound spectrum takes the form of reverberation from whatever it sits on, be it a table top or the floor.

Employing elements of robotic technologies, the device can move its arms, shoulders, and wheels (it has six moving parts) to the beat of the music, and it can generate about 700 different colors for lighting effects. Rolly comes preprogrammed with some dance routines, but you can also add your own choreography via a PC and USB connection. With 2 GB of Flash memory, you get a storage capacity of 500+ songs in MP3 format.

The gadget is already available in Japan and should be in US stores shortly after you read this. No price has been announced as of this writing, but they sell for about \$350 in Japan, which seems like a dubious buck-to-bang ratio. **NV**

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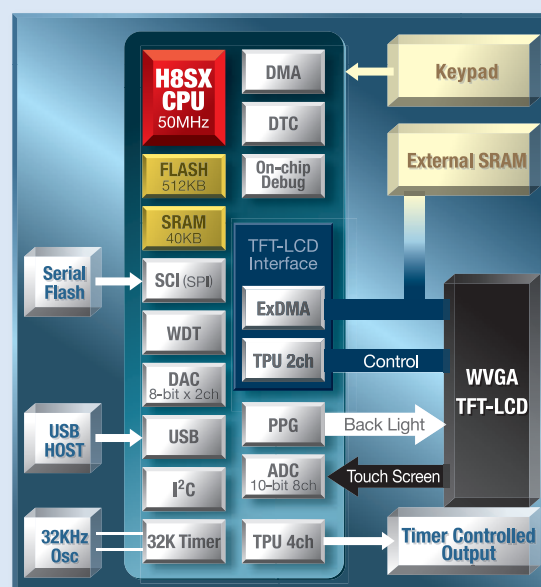
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 - 32KHz clock input with timer
 - Full Software API with complex LCD images supported
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*Source: Gartner (March 2007) "2006 Worldwide Microcontroller Vendor Revenue" GJ07168



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GETTING STARTED WITH PICs

THE LATEST IN PROGRAMMING MICROCONTROLLERS

■ BY CHUCK HELLEBUYCK

ASSEMBLY LANGUAGE PROGRAMMING

WHEN I STARTED PROGRAMMING MICROCONTROLLERS (MCUs), assembly language was the only real choice. I didn't even know what a compiler was. Now, it seems many beginners and even experienced programmers tend to fear — or at least try to avoid — using assembly language. I will admit that the latest variety of C compilers and Basic compilers make programming much easier, but I still feel it is necessary for a programmer to understand enough about assembly language to write a simple program that lights or blinks an LED. I plan to show how to do this with the Microchip PIC16F690 MCU.

I will use the PICkit™ 2 starter package, which includes a development board and PIC16F690. This makes the hardware easy to set up and use. I will also use Microchip Technology's MPLAB® Integrated Development Environment (IDE) software to write, assemble, and control the PICkit 2 programmer. (I've discussed this

programmer many times before.)

Using the MPLAB IDE may be a little confusing to the beginner, but I recommend it because — first of all — it's free to download. The MPLAB IDE also comes with assembler software, which is automatically loaded on your computer when you install the MPLAB IDE. If you want help getting started

with the MPLAB IDE, Microchip offers a great tutorial that you can download at http://techtrain.microchip.com/webseminars/documents/IntroToMPLAB_033004.pdf.

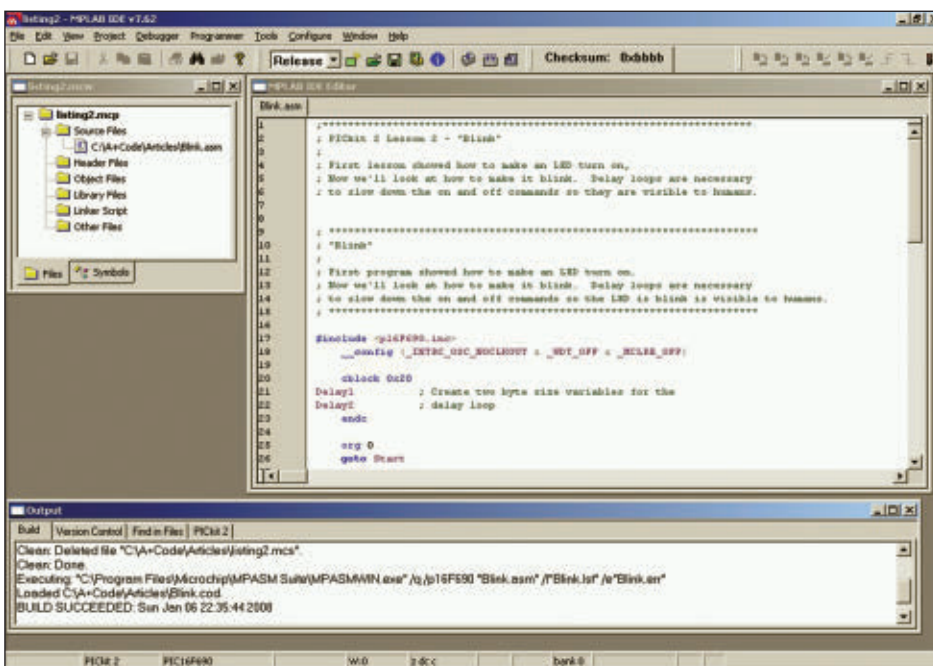
It is a little dated since the MPLAB IDE software version used is 6.42 and the latest release is 8.00, but the summary of how to use the project wizard and then navigate the IDE is very similar — so this should get you going. Figure 1 shows the MPLAB environment.

ASSEMBLY LANGUAGE

If you develop your code for a C compiler or Basic compiler, the compiler will convert your program into assembly language and then

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The complete code listings for Listings 1 and 2 are available on the *Nuts & Volts* website at www.nutsvolts.com



■ FIGURE 1. MPLAB® IDE.

assemble the file into the binary 1s and 0s that make up the .hex file the PICkit 2 will Flash into the MCU. By learning assembly language, you are just skipping the compiler stage as the rest of the process is the same.

Assembly language commands can look very cryptic, but after you use them for a little while you will find they are just a few letter abbreviations for what the commands accomplish. On the PIC16F690, there are 35 assembly language instructions but in most cases, you will only use about half of them. To really understand and use assembly language, you really only need to memorize about 20 commands or less.

The biggest confusion I find beginners have with assembly is the memory structure of the smaller PIC16F family MCUs. The control registers are multiplexed in a bank arrangement to share address lines. This means you have to set or clear a bit in the Status register to jump to the proper bank of memory and access certain registers. Once you see it done though, it's easy to follow and use. Compilers tend to handle this for you, so you don't have to deal with it.

LIGHT AN LED

I figure that the best way to show assembly language is to jump right into a project. The project in Listing 1 is a simple program that lights an LED connected to the PortC pin 0 of the PIC16F690. The DS1 LED of the PICkit 2 development board already has the pin connected to a resistor that is in-series with an LED, with the cathode connected to ground. A high on PortC pin 0 will light the LED; a low will shut it off. If you've used microEngineering Labs' PICBASIC PRO compiler (which I've mentioned in this column many times before), you know how easy performing this function can be. A simple "High PortC.0" command will get the job done. What is underneath that simple command line, though, are several assembly language commands.

Listing 1 shows an example of an assembly language routine to light the LED. As you will notice, it is a lot longer than the simple PICBASIC PRO command line though, in reality, it may not take up any more program memory space. Some of the program structure in Listing 1 also includes the setup and configuration information that PICBASIC PRO handles with an include file. It is typical of a compiler to hide a bunch of details in other include files to make writing the software easier for you.

Let me step through the various sections of Listing 1, to help you understand what is going on.

Right at the top of the program is a "#include" command that indicates which processor file to include. This .inc include file has all the inner details of the PIC16F690, such as register locations and names of the various special function registers the program may reference. This is very similar to a .h header file in C language, and PICBASIC PRO has .inc files that it calls in the background during compile time.

```
#include <p16F690.inc>
```

The next line I show is for the configuration fuses. These set the various options, such as oscillator selection (internal oscillator), watchdog timer (disabled), and master

clear pin (internal). There are other configuration fuses and the definition of these rests in the p16F690.inc file. You can actually leave this line off, but then you have to manually set these fuses in the programmer's software or the MPLAB IDE configuration settings under the Configure > Configuration Settings... menu option.

```
__config (_INTRC_OSC_NOCLKOUT & _WDT_OFF & _MCLRE_OFF)
```

The "org 0" line really starts the assembly language program. The MCU will jump to location zero of memory after a reset condition or power-up. Therefore, we have to tell the program where to go by placing a command at memory location zero. The org 0 directive tells the assembler to place the next command at memory location zero. That command is the "goto Start" command line. You've probably seen the GOTO command in many other languages, so this is pretty universal and easy to understand. You can already see that some of the assembly commands are not tough to figure out at all. The label "Start" is just a label that shows up further down in the program. So, when the MCU is reset, the first thing it will do is jump to the label Start.

```
org 0
goto Start
```

Another org directive is used to position the beginning of the main program. Inside the PIC16F690, interrupts will automatically jump to memory location four, so the main loop of code needs to be placed after the interrupt location. We do that by simply creating an org 5 statement. Any commands after the org 5 statement will be placed at memory location five. The label Start is after the org 5, so that label equates to memory location five but it's not a command. The first command at location five is the bsf STATUS, RP0 command line.

```
org 5

Start
bsf          STATUS,RP0      ; select Register Page 1
```

The "BSF" is an assembly command that is an abbreviation for Bit Set File register, or set a specific bit in a defined special function register. In this case, the special function register is the STATUS register. The RP0 in the command is the individual bit location to set. The RP0 bit determines which bank of memory to address. Remember that I mentioned the memory in the smaller PIC MCUs is banked? The next command will modify the TRISC register, which is located on Bank 1 of the PIC16F690 memory map. So, we need to first switch over to Bank 1 before operating on the TRISC register. To do that, we set the RP0 bit of the STATUS register with the BSF command.

We want to make the PortC pin 0 an output to drive the LED. That bit in the TRISC register needs to be cleared, to make PortC pin 0 an output. Therefore, the command BCF (Bit Clear File) is doing just that, clearing the proper bit in the TRISC register.

```
bcf          TRISC,0          ; make IO Pin C0 an output
```

We don't need to access any other registers on Bank 1 of memory, so we need to reset program control back to

Bank 0. We do that by clearing the RP0 bit in the STATUS register. Remember we set it with the BSF command to move to Bank 1, so now we need to BCF or bit clear the same bit to put control back at Bank 0.

```
bcf        STATUS,RP0      ; back to Register Page 0
```

Finally, we turn on the LED by placing a high level on the PortC pin 0. We use an already familiar command BSF to set the PortC pin 0 bit in the PORTC data register. By setting that bit to a 1 or high value, the LED will light. The PORTC register is in Bank 0 of program memory. You can see where these different special function registers are by looking at the memory map in the datasheet for the part you are using.

```
bsf        PORTC,0         ; turn on LED C0 (DS1)
```

Finally, we issue a GOTO command again; but instead of going to a label we use the assembler's special character "\$," which represents the value of the current program counter location. The program counter is pointing to the GOTO command when it gets here, so all it is saying is goto the same spot where you currently are. I could have put a label above the GOTO command and then put that label in the GOTO command line; but instead I chose to show that sometimes little symbols that make assembly coding confusing are really just shortcuts, and not actual assembly commands.

```
goto      $                ; wait here
```

The last step is to issue the assembly command to end the program. This is a safe way to mark the end of the program, and should be part of all assembly language code.

```
end
```

As you can see, we only used four assembly language commands — BSF, BCF, GOTO, and END — to light an LED. This wasn't that difficult to understand, and should begin to make you feel a little more comfortable with understanding assembly code.

BLINK AN LED

Lighting an LED is a great start, but that can be accomplished with a battery and resistor. Getting an LED to flash takes a little more effort and is a better demonstration of a MCU's capabilities. So, I'll expand on the previous example to show how to blink the LED and also add a delay, so the LED blinks slow enough for the human eye to see it. The program in Listing 2 shows the "Blink an LED" routine. I'll step through that program to show how delays work.

The top of the program is the same as Listing 1, where we indicate the MCU being used and the configuration fuses.

```
#include <p16F690.inc>
__config (_INTRC_OSC_NOCLKOUT & _WDT_OFF &
_MCLRRE_OFF)
```

For this program, we need to establish a few variables in RAM to store the delay time count value. Using the assembler directive "cblock," we establish a block of RAM starting at address 20 hex. If you look at the PIC16F690 datasheet's

memory map page, you'll see that the general-purpose register locations start at memory location 20h. It has a total of 96 bytes of space in the memory block, so we can fit 96 bytes of variables in this bank of memory. In this example we only need two, which I call Delay1 and Delay2. Other banks have more space for variables, if we need more than 96. The "endc" directive indicates the end of the cblock.

A cblock is defined as a way to designate a block of constants (constant block) with a specific starting address, and then each label increments one byte off that starting location. In the assembler, though, this isn't really a constant value, it's a constant location. The assembler manual even states, "when creating non-relocatable (absolute) code, cblock is often used to define variable address location names." So, don't let the C in cblock confuse you into thinking it only works for constant values. You have more freedom in assembly programming, since you are controlling memory directly — not through some compiler's rules.

```
cblock 0x20
Delay1      ; Create two byte size variables for the
Delay2      ; delay loop
endc
```

The now familiar org 0 and org 5 statements are implemented the same way as before, by marking the program memory locations. Also, the setting of the TRISC register is identical to the previous example.

```
org 0
goto Start

org 5
Start
bsf        STATUS,RP0      ; select Register Page 1
bcf        TRISC,0         ; make IO Pin C0 an output
bcf        STATUS,RP0      ; back to Register Page 0
```

The main loop is where the program begins to change. The first command issued is the BSF command, to light the LED on PortC pin 0 with a high value.

```
MainLoop
bsf        PORTC,0         ; turn on LED C0
```

Now that the LED is on, we need to keep it on for a period long enough for the human eye to see it. If we don't delay, the program will flash the LED too fast; as each assembly instruction only takes one clock cycle. If we are running with a 4 MHz internal oscillator, which then gets divided by four internally for the system instruction clock, the instruction clock is functioning each assembly command at one million instructions per second, or one microsecond each. Therefore, we need to add a significant number of loops to kill time, and this is where those variables Delay1 and Delay2 come in.

As you can see in the block of code that follows, we first decrement the value of Delay1 with a "DECFSZ" command, which stands for Decrement File register by one and Skip the next instruction if zero. Delay1 will decrement from 0 to FF hex, so it's not zero when tested, and the "GOTO OndelayLoop" command line is implemented by putting the program back to the DECFSZ command. This continues for

256 loops and then jumps to the DECFSZ command, which operates on the Delay2 variable. If Delay2 is not zero, then the GOTO OndelayLoop command line puts us back to working on the Delay1 variable 256 more times.

I mentioned that all assembly instructions take one clock count, but actually GOTOs take two. So, that first loop takes three clock counts (DECFSZ + GOTO). The second loop also uses three clock counts each time it jumps us back to the OndelayLoop label. If I multiply all this out, I get $[(3 * 256) + 3] * 256 = 197,676$ instructions. At the one microsecond per instruction speed, that equates to 197.676 microseconds or close to 200 milliseconds of delay. That is slow enough for the human eye to see it.

```
OndelayLoop
  decfsz    Delay1,f      ; Waste time.
  goto      OndelayLoop  ; The Inner loop takes
                          ; 3 instructions per
                          ; loop * 256 loops =
                          ; 768 instructions
  decfsz    Delay2,f      ; The outer loop takes
                          ; and additional 3
                          ; instructions per loop
                          ; * 256 loops
  goto      OndelayLoop  ; (768+3) * 256 =
                          ; 197376 instructions /
                          ; 1M instructions per
                          ; second = 0.197 sec.,
                          ; call it a two-tenths
                          ; of a second.
```

The next instruction simply BCFs the PortC pin to put the LED at a low voltage, and the LED is off.

```
bcf        PORTC,0        ; Turn off LED C0
```

We add another delay with a different label, to create the off delay of 200 microseconds.

```
OffDelayLoop
  decfsz    Delay1,f      ; same delay as above
  goto      OffDelayLoop
  decfsz    Delay2,f
  goto      OffDelayLoop
```

A simple GOTO command puts the program back at the top to do it all again, thus creating a blinking LED.

```
goto      MainLoop        ; Do it again...
```

An END command closes out the program.

```
end
```

CONCLUSION

I can only cover so much territory in a short magazine article, but hopefully I broke down these simple programs enough so you can understand that assembly language is not so scary. Some will say, "why write all that code when a few lines of PICBASIC PRO will accomplish the same task?" The reason is precision. There are times when you need to know exactly how much time it takes to do a certain task, and the compiler you choose — C or PICBASIC PRO or any other — may not offer that level of detail or allow you to get down to the accuracy you need. That is why most compilers allow you to insert assembly code inside the C or Basic program. Having the assembly language background makes you far more prepared to solve your application's accuracy problems.

The Microchip assembler manual can be downloaded from: <http://ww1.microchip.com/downloads/en/DeviceDoc/33014j.pdf>. This will give you all the details you need on how to write assembly code. Microchip even offers classes on how to use the MPLAB IDE and assembly at their Regional Training Centers (RTC). You can find the latest classes and RTC locations by visiting the website at www.microchip.com/rtc. Most classes are \$49 for a half day and \$99 for a full day. I recommend you check them out.

As you can see, my column has changed to every other month, which leaves me less time to update you on everything new. If you have an idea for a future column or just a question, please send your feedback to chuck@elproducts.com. I do try to answer every email. Until next time, keep on programming ... **NV**

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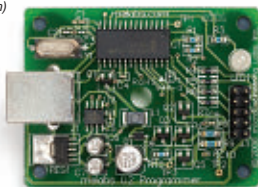
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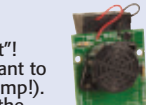
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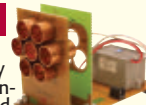
This little \$8 kit can really "bail you out"! Simply mount the alarm where you want to detect water level problems (sump pump!). When the water touches the contacts the alarm goes off! Sensor can even be remotely located. Runs on a standard 9V battery.



MK108 Water Sensor Alarm Kit \$7.95

Air Blasting Ion Generator

Generates negative ions along with a hefty blast of fresh air, all without any noise! The steady state DC voltage generates 7.5kV DC negative at 400uA, and that's LOTS of ions! Includes 7 wind tubes for max air! Runs on 12-15VDC.



IG7 Ion Generator Kit \$64.95

IC AM/FM Radio Lab

Learn all about AM/FM radio theory, IC theory, and end up with a high quality radio! Extensive step-by-step instructions guide you through theory, parts descriptions, and the how's and why's of IC design. Runs on a standard 9V battery.



AMFM108K AM/FM IC Radio Lab Kit \$34.95

Practice Guitar Amp & DI

Practice your guitar without driving your family or neighbors nuts! Works with any electric, acoustic-electric, or bass guitar. Plug your MP3 player into the aux input and practice to your favorite music! Drives standard headphones and also works as a DI for any home stereo!



PGA1 Personal Practice Guitar Amp Kit \$64.95

Laser Light Show

Just like the big concerts, you can impress your friends with your own laser light show! Audio input modulates the laser display to your favorite music! Adjustable pattern & speed. Runs on 6-12VDC.



LLS1 Laser Light Show Kit \$44.95

Voice Activated Switch

Voice activated (VOX) provides a switched output when it hears a sound. Great for a hands free PTT switch or to turn on a recorder or light! Directly switches relays or low voltage loads up to 100mA. Runs on 6-12 VDC.



VS1 Voice Switch Kit \$9.95

Touch Switch

Touch on, touch off, or momentary touch hold, it's your choice with this little kit! Uses CMOS technology. Actually includes TWO totally separate touch circuits on the board! Dries any low voltage load up to 100mA. Runs on 6-12 VDC.



TS1 Touch Switch Kit \$9.95

DTMF Encoder Decoder

Decodes standard Touch Tones from telephones, radio, or any audio source. Detects and decodes any single digit and provides a closure to ground up to 20mA. Great for remote tone control. Runs on 5VDC.



TT7 DTMF Encode/Decode Kit \$24.95

RF Actuated Relay

Just what you need when adding a preamp or power amp in line with an antenna! Auto senses RF and closes an on-board DPDT relay that's good to UHF at 100W! Also great to protect expensive RF test equipment. Senses as low as 50mW! Runs on 10-15VDC.



RFS1 RF Actuated Relay Kit \$19.95

Tickle-Stick Shocker

The kit has a pulsing 80 volt tickle output and a mischievous blinking LED. And who can resist a blinking light and an unlabeled switch! Great fun for your desk, "Hey, I told you not to touch!" Runs on 3-6 VDC.



TS4 Tickle Stick Kit \$12.95

SMT Multi-Color Blinky

The ultimate blinky kit! The 8-pin micro-controller drives a very special RGB LED in 16 million color combinations! Uses PWM methods to generate any color with the micro, with switchable speed selection. SMT construction with extra parts when you lose them! Runs on 9V battery.



SBRGB1 SMT Multi-Color Blinky Kit \$29.95

Passive Aircraft Monitor

The hit of the decade! Our patented receiver hears the entire aircraft band without any tuning! Passive design has no LO, therefore can be used on board aircraft! Perfect for air-shows, hears the active traffic as it happens! Available kit or factory assembled.



ABM1 Passive Aircraft Rcvr Kit \$89.95

Electronic Siren

Exactly duplicates the upward and downward wail of a police siren. Switch closure produces upward wail, releasing it makes it return downward. Produces a loud 5W output, and will drive any speaker! Horn speakers sound the best! Runs on 6-12 VDC.



SM3 Electronic Siren Kit \$7.95

Tone Encoder/Decoder

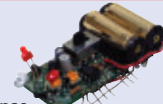
Encodes OR decodes any tone 40 Hz to 5KHz! Add a small cap and it will go as low as 10 Hz! Tunable with a precision 20 turn pot. Great for sub-audible "CTS" tone squelch encoders or decoders. Drives any low voltage load up to 100mA. Runs on 5-12 VDC.



TD1 Encoder/Decoder Kit \$9.95

Walking Electronic Bug

Built around a pair of subminiature cell phone motors, this bug wanders around looking for things to bump into! Sensors below his LED eyes sense proximity and make him turn away! Steer him with flashlights too! Runs on two "N" batteries.



WEB1 Walking Bug Kit \$29.95

Super Snoop Amplifier

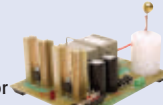
Super sensitive amplifier that will pick up a pin drop at 15 feet! Full 2 watt output drives any speaker for a great sound. Makes a great "big ear" microphone to listen to the "wildlife" both in the field and in the city! Runs on 6-15 VDC.



BN9 Super Snoop Amp Kit \$9.95

HV Plasma Generator

Generate 2" sparks to a handheld screwdriver! Light fluorescent tubes without wires! This plasma generator creates up to 25kV at 20kHz from a solid state circuit! Build plasma bulbs from regular bulbs and more! Runs on 16VAC or 5-24VDC.



PG13 HV Plasma Generator Kit \$64.95

Stereo Ear Super Amplifier

Ultra high gain amp boosts audio 50 times and it does it in stereo with its dual directional stereo microphones! Just plug in your standard earphone or headset and point towards the source. Great stereo separation besides! Runs on 3 AAA batteries.



MK136 Stereo Ear Amplifier Kit \$9.95

3-In-1 Multifunction Lab

The handiest item for your bench! Includes a RoHS compliant temp controlled soldering station, digital multimeter, and a regulated lab power supply! All in one small unit for your bench! It can't be beat!



LAB1U 3-In1 Multifunction Solder Lab \$129.95



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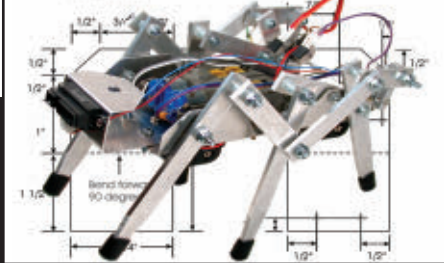
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PERSONAL ROBOTICS

UNDERSTANDING, DESIGNING & CONSTRUCTING ROBOTS & ROBOTIC SYSTEMS

■ BY VERN GRANER

VIRTUAL ROBOTICS: Can you work with robotics if you don't have a robot?

DUE TO A LIFELONG LOVE AFFAIR WITH ALL THINGS ELECTRONIC, at any given moment I am within arm's reach of a number of robotic and electronic parts and tools. Servos and circuit boards decorate my desk, breadboards and batteries abound on my workbench, and the subtle bouquet of solder flux seems to linger in the air. Subsequently, when I want to experiment with electronics or try out a robotic idea, I can usually lay my hands on some parts in short order and just hook stuff up to see what happens. This, of course, isn't always the case. When I travel, I've discovered that it is not a good idea to stash tools, PC boards, and batteries in your carry-on luggage (especially big red LED displays that count backwards in seconds towards zero ... don't ask). So, the robots, parts, and tools are abandoned at home.

The Traveling Roboticist is not the only one faced with the issue of having no toy equipment on hand. I've received a number of emails from readers who have asked for information about getting started in robotics or ways to explore robotics on a low (read: zero) budget. Some have experience in associated technical areas like

radio or analog circuitry and are interested in what it would take to cross over to robotics. Others have programming background but are attracted to the motion of robotics, but are not sure if they would have a sustained interest that would support an investment in parts, tools, and books. Still others have been eyeing the field from afar wondering how to "get there from here." In these situations where an investment of space, money, time, or interest is in question, there is usually one common solution: a personal computer.

Reality" (or VR) was a popular concept. Lots of companies came out with ultra geeky heads-up display helmets, actuator gloves, and other I/O devices to allow a user to immerse themselves in virtual worlds and simulations. After a while, developers discovered they could build virtual items using just the PC itself without the need for these cumbersome hardware I/O devices.

Using just a PC, it's possible to have entire virtual worlds, featuring simulated physics and even photo-realistic depictions of objects and environments. But before we jackrabbit ahead to Virtual Robots sporting Newtonian physics, let's slow down a bit and start with simple simulation using just your PC and a turtle.



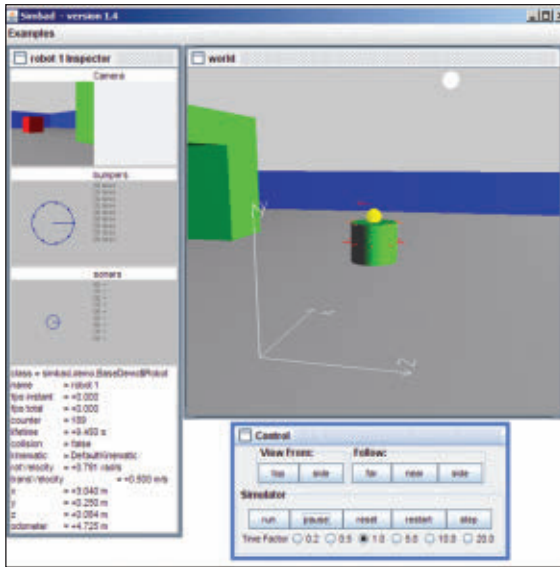
VIRTUAL REALITY — THE GLOVES ARE OFF!

In the '80s, "Virtual

■ FIGURE 1. The LOGO Foundation.

LOCO FOR LOGO!

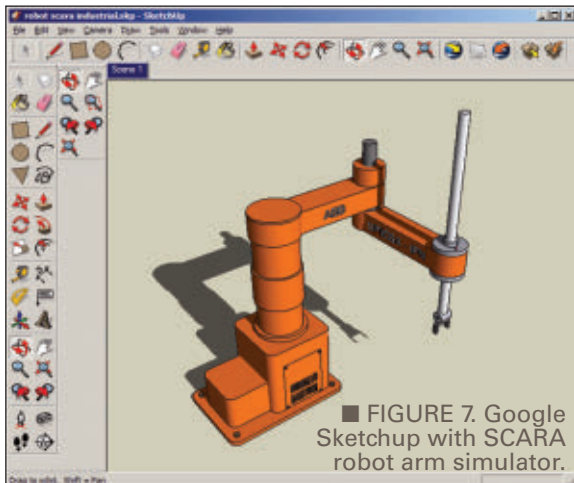
Created back in 1967 by Wally Feurzeig and Seymour Papert, LOGO is a programming language that is still



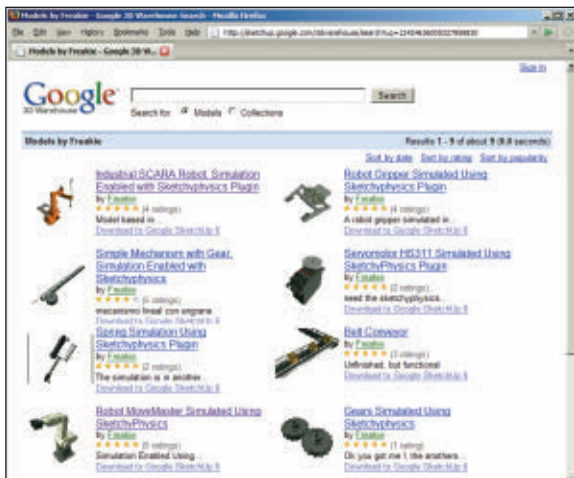
■ FIGURE 5. Simbad simulator.

SAILING ON WITH SIMBAD

For fans of open FOSS, Simbad is the way to go for robotics simulation.



■ FIGURE 7. Google Sketchup with SCARA robot arm simulator.



■ FIGURE 6. Download page for Google Sketchup.

Simbad is obviously designed with the professional researcher or programmer in mind. It's a definite must-have application for a long plane flight as it allows you to really experiment!

SKETCH IT UP, I'LL TAKE IT!

Hosted on Source Forge and distributed under the GNU public license, Simbad's JAVA roots make it compatible with a plethora of platforms. I used the JAVA version under Windows XP with no trouble at all and was delighted with the capabilities of this product (Figure 5). This is serious simulation software for doing advanced robotics research. From their website:

"Simbad is a Java 3D robot simulator for scientific and educational purposes. It is mainly dedicated to researchers/programmers who want a simple basis for studying Situated Artificial Intelligence, Machine Learning, and more generally AI algorithms, in the context of Autonomous Robotics and Autonomous Agents. It is not intended to provide a real world simulation and is kept voluntarily readable and simple. Simbad enables programmers to write their own robot controller, modify the environment, and use the available sensors. Don't think of it as a finite product but merely as an opened framework to test your own ideas."

■ FIGURE 8. Google 3D Warehouse with pre-made robotic parts.

If serious three dimensional drawing is what you're after, Google has made available an amazing CAD tool called Google Sketchup that can be used to model all kinds of objects. Though available as a free download (Figure 6), they also offer a pro version for \$500. Since Google has such a vast presence on the Internet, the user base for this program is huge, and the libraries of free models is simply stunning. Sketchup can support plug-ins that expand its functionality. One such is the "Google Sketchy Physics" module. This plug-in allows you to apply Newtonian physics to your models in real time.

One of the first models I found in searching for robotics was a complete SCARA (Selective Compliant Assembly Robot Arm) model with real physics (Figure 7)! And this was just the beginning. If you go to the Google Sketchup 3D Warehouse, you can search through tons of models (Figure 8) so you don't have to re-invent the wheel. (Literally! you can download models of wheels!) Lots of other robotic parts and even complete robotic systems have also already been modeled and are ready to be downloaded and assembled into your own virtual bot (Figure 9).

THIS IS THE DROIDQUEST YOU ARE LOOKING FOR!

For those of you who remember the Apple II computer, you may be



■ FIGURE 9. Google 3D warehouse complete robotic arm model.

delighted to find that a very popular educational game is still alive and doing fine on the Internet. Robot Odyssey, developed back in 1984 by The Learning Company, taught the basics of programming by presenting challenges that were solved by wiring together logic gates. Rescued from the digital garbage heap by Thomas Foote, this game has been reborn and dubbed "Droid Quest."

Implemented in JAVA (thereby making it compatible with Linux, Mac, and the Windows world), this game is a wonderful way to approach the otherwise somewhat dry and confusing world of logic circuits and how they interact. Though the graphics are quite faithful to the original eight-bit Apple program (Figure 10), it only takes a little playing time to see through the clunky, blocky figures to the underlying exciting challenges.

Originally designed for kids, the game also works well for adults and has the ability to provide a good foundation in the basic building blocks of robotics to anyone who plays it. It's a free download from www.droidquest.com.

LOSE SCOPE? WINSOPE!

So now that we've looked over some simulators, let's have a look at some virtual tools you can get just by downloading them to your hard drive!

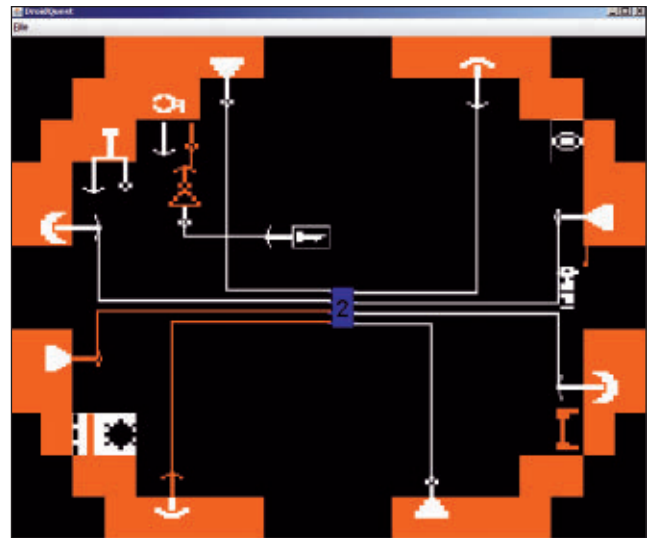
One of the more common tools used in robotics is the venerable oscilloscope. If you'd like to have one for experimentation, you can get a free software-based scope that uses your sound card to sample events and display the traces on your computer screen. WinScope (Figure 11) by Konstantin Zeldovich is available for free and does a pretty good job of showing frequencies and waveforms in the 20 kHz and less range. Though not as advanced as a real scope or even some of the hybrid hardware/software scope offerings, if you just need to see a pulse train or want to experiment with a scope before buying one, this little utility is perfect.

Though still available on the Internet from various sources (see the resource section for links) for free, an updated commercial version has become available from the original author for \$20.

THE TOOL THAT NAMES ITSELF!

The aptly named "Frequency Analyzer" is a nice little spectrum analyzer that offers a visual glimpse into the

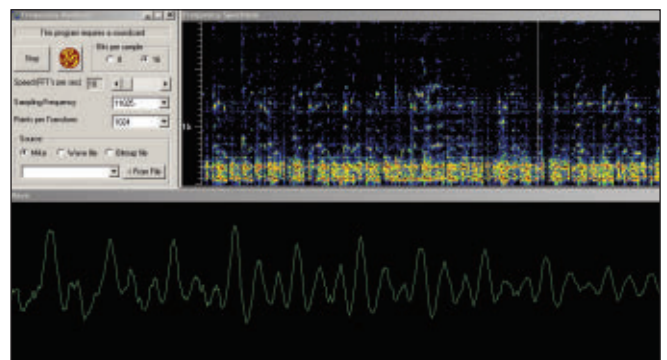
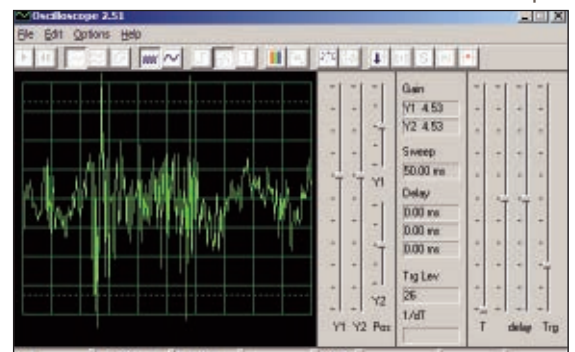
■ FIGURE 12. Software based frequency analyzer.

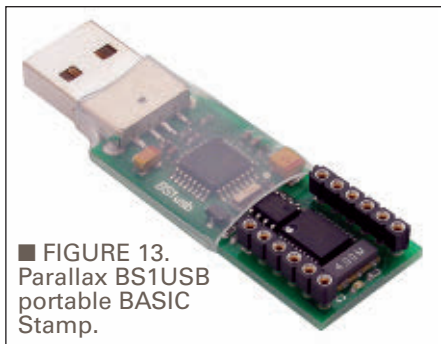


■ FIGURE 10. DroidQuest educational game.

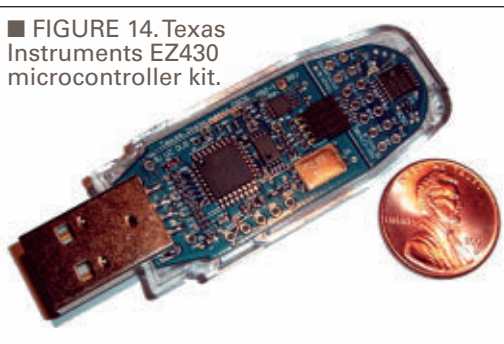
audible world (Figure 12). Sporting both a waveform display like an oscilloscope and a color graphic FFT (Fast Fourier Transform) display, you can use this virtual tool to see how frequencies are concentrated across the spectrum in real time! This program is not only available as a free download; Reliable Software has the source code available, as well. This makes it possible for you to examine and learn how to write software tools

■ FIGURE 11. WinScope software oscilloscope.





■ FIGURE 13. Parallax BS1USB portable BASIC Stamp.



■ FIGURE 14. Texas Instruments EZ430 microcontroller kit.

practically giving the kit away for a measly \$20. For those of you who would like to sharpen your programming chops on the road, this nifty device is a must-have.

VIRTUALLY DONE!

I'm sure I have only scratched the surface here and that some of you may have favorite programs that were overlooked. Please feel

PLEASE NOTE

At the time of writing, all the software detailed in this article was available on the Internet for download free of charge at the links detailed in the resources section. If a paid version was available (i.e., "upgrade" or "pro" version), I tried to include the stated price. Many of the programs require Microsoft Windows to operate, though some have alternate versions for different OSs. It should also be noted that I am not affiliated with any of these software companies and that my comments are my opinions based on a small amount of experimentation with each program described. I wish to thank all the software authors for making such great programs freely available to us.

of your own. Available from the "Freeware" section on their website.

LILLIPUTIAN PORTABLE PROGRAMING PRODUCTS

Though I've focused on the software-based virtual offerings throughout this column, I wanted to point to a couple of very cool (and tiny!) pieces of real hardware that are especially interesting if you travel or don't have the

room or bucks for a lot of equipment.

IS THAT A MICROCONTROLLER IN YOUR POCKET ... ?

Our good friends at Parallax have once again come up with a neat little solution to BASIC Stamp coding on the run. The BS1USB (Figure 13) is a small memory stick sized BASIC Stamp that is completely self-contained, drawing power from the USB port on your computer and allowing you to simply plug it in and program. The device has a small DIP socket that provides ready access to power, ground, and eight I/O pins for small-scale experiments. It's \$39.95 from the Parallax website.

ITTY BITTY TI

The folks at Texas Instruments have a neat little memory stick sized programming environment called the TIMSP430 (catchy name, eh?) that not only offers programmability, but also sports dime-sized interchangeable modules so you can work on different projects at will (Figure 14). TI is

free to email me with your favorites and recommendations. In the meantime, I hope that some of the offerings above have whetted your appetite for working with robotics even if you don't have the space, time, or money to buy all the latest devices. With a PC, you should be able to experiment and play with robotics without a bucket full of gadgets at your beck and call. Of course, this is not to say that a bunch of spare parts and a well-stocked workbench aren't helpful! In fact, if you're looking at building your first workbench or remodeling your old one, keep an eye out for an upcoming article where I feature the "Habitat for Hobbies" featuring workbench designs for robotics and electronics hobbyists.

For those of you that have been in the game for a while (you know who you are!), please take a few photos of your workspace and email them to me. Include a description of what you consider to be must-have items and a short summary of what you would do differently if you had it to do all over again. Don't be shy! Send in pictures of your work area just the way it is, messy or meticulous! Send submissions to the author at vern@txis.com. **NV**

RESOURCES

SOFTWARE LINKS

■ The LOGO Foundation
<http://el.media.mit.edu/logo-foundation>

■ MSWLogo for Windows
www.softronix.com

■ BugWorks
www.bugworks.org

■ JUICE
www.natew.com/juice

■ Simbad
<http://simbad.sourceforge.net>

■ Google Sketchup
<http://sketchup.google.com>

■ Google Sketchy Physics Plug-in
<http://code.google.com/p/sketchyphysics>

■ DroidQuest
www.DroidQuest.com

■ WinScope Free Version Sources
www.geocities.com/nlradiofm/winscope.zip

www.notepad.org/WinScope.zip

www.amt.org/Downloads/osc251.zip

■ WinScope — Upgraded Commercial Version
www.zelscope.com

■ Reliable Software's Frequency Analyzer
www.relisoft.com/freeware

HARDWARE LINKS

■ Parallax BS1USB Board
www.parallax.com

■ Texas Instruments MSP430 USB Stick
www.ti.com/ez430

Amazing Devices

www.amazing1.com

See website for further descriptions

Laser Pointers and Modules

LAPNGR5U - 5 mw green laser pointer \$59.95

LAPNGR60 - More than or equal to 60mw - Class 3B \$239.00

LAPNGR195 - More than or equal to 165mw - Class 3B \$675.00

These lasers will burn at a distance!!!

Red - Class IIIa 3 volt modules

LM650P3 - 3mw 650 nm 12 x 45 mm \$14.95

LM650P5 - 5mw 650 nm 12 x 45 mm \$24.95

LM630P3 - 3mw 630 nm 10.5 x 45 mm \$34.95

Red - Class IIIB

LM650P10 - 10mw 650 nm 12 x 51 mm \$99.95

Laser Diode Visible Red - Class IIIB

LD630-P10 - 10mw 635 nm 5 mm diode \$9.95

Green - Class IIIa 3 volt modules

LM532P5 - 5mw 532 nm 12X45 mm \$39.95

Infrared - Class IIIB 3 volt modules

LM580P30 - 30mw 980 nm 12X30 mm \$49.95

High Voltage Capacitors

270/3KV - 270 pfd 3kv .3" d x .25" \$25.45 each

500/10KV - 500 pfd 10kv .35" d x .25" \$25.75 eac

500/30KV - 500 pfd 30 kv .5" d x .4" \$2.95

1000/20KV - 1000 pfd 20kv .5" d x .37" \$2.25

.01/2KV - .01mfd 2kv .63" x .13" \$5.00

STACKA - 12 stages at 12 kv each for mini-multipliers \$24.95

High Voltage Transformers

Includes circuit schematics on how to use.

28K089 - 7kv 10ma 30khz 9-14v 1" cube \$19.95

28K074 - 4kv 15ma 30khz 9-14v 1" cube \$17.95

28K077 - 2kv 10ma 30khz 7-9v .7x 1.25 \$9.95

CD25B - 20 kv trigger pulse 1 x 1.25 \$16.95

CD45 - 40 kv trigger pulse 1.25 x 1.25 \$18.95

TRAN1035 - 10kv 35 ma bal output \$39.95

FLYLABURN - 10 kv 60 ma endgrd \$49.95

FLYEXP - 7 misc flybacks \$34.95

FLYPVM400HP - High power flyback \$34.95

High Volt/Freq Modules

12 vdc with instructions on how to use.

MINIMAX2 - 2kv 10 ma 50 khz \$17.95

MINIMAX3 - 3kv 10 ma 35 khz \$19.95

MINIMAX7 - 7kv 10 ma 35 khz \$34.95

SS01S - 1 to 7kv ac for ozone \$24.95

GRADIRV10 - 7.5kv 15 ma 35 khz adj \$79.50

PVM400 - 20kv 25ma 115vac input \$189.95

High Volt DC Modules

12 vdc with instructions on how to use.

PBK40 - 10 kv 100ua 9 vdc in \$34.95

CHARGE10 - 10kv 2.5 ma \$59.95

TRIG10 - 20 kv trigger/shock pulses \$54.95

SS016S - +20kv 100ua \$29.95

SS010S - Minus 20kv for neg ions \$24.95

HV250 - 25,000 volt power supply \$39.95

Parts for Tesla Coils

Includes plans for a TESLA coil. Parallel for 60&120ma.

4KV1.03 - 4kv 30ma 60hz floating output \$59.95

6KV1.02 - 6kv 20ma 60hz floating output \$59.95

9KV1.03 - 9kv 30ma 60hz midgrd output \$79.95

12KV1.03 - 12kv 30ma 60hz midgrd output \$109.95

15KV1.03 - 15kv 30ma 60hz midgrd output \$139.95

14.4KV1.5A - 14.4kv .5amp pole pig POR

Spark Gaps and Electrodes

SPARK1 - Fan cooled dual gap 3/8" tungsten \$149.95

SPARK05 - Single gap 1/4" tungsten \$49.95

TUNG141B - 1/4" x 1" pair electrodes with holders tungsten \$14.95

TUNG38 - 3/8" x 2" pair electrodes with holders tungsten \$59.95

Toroidal Terminals

TO8 - 8 x 2" Spun Aluminum Toroid \$59.95

TO12 - 12 x 3" Spun Aluminum Toroid \$79.95

TO24 - 24 x 6" Spun Aluminum Toroid \$399.95

TO30 - 30 x 7" Spun Aluminum Toroid \$525.95

See website for more data on above items

Minimum order is \$10.00. Volume pricing available

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Q&A

WHAT'S UP:

Join us as we delve into the basics of electronics as applied to every day problems, like:

- ✓ Electric Car Battery Charger
- ✓ How to Monitor Series Cells
- ✓ Audio Amplifiers

■ WITH RUSSELL KINCAID

In this column, I answer questions about all aspects of electronics, including computer hardware, software, circuits, electronic theory, troubleshooting, and anything else of interest to the hobbyist. Feel free to participate with your questions, comments, or suggestions.

Send all questions and comments to:
Q&A@nutsvolts.com

X-10 PROBLEM

Q The X-10 appliance module is great for in-house control. The problem I have is with the new compact fluorescent lights. When you turn off the X-10, there is enough leakage current that the CFL will flash once or twice a second. Not a complete lighting of the whole tube, but enough that it is distracting and a waste of energy. (True for units with or without the sense line cut.)

A couple of tests show that a small (4W) incandescent night light in parallel with the CFL takes care of the leakage current and the CFL won't flicker, and there is not enough current so the incandescent doesn't light. (Still wasting energy, but oh well.) Great! But ... when you turn the CFL on, the night light also comes on — another unneeded light, expense, and waste of energy.

What I need is a circuit that is small, cheap, and safe that I could put under the socket of a table lamp with a CFL, or in a dummy plug to be plugged in alongside the lamp into the X-10 that

would take care of the leakage current when the X-10 is off so the CFL doesn't flicker, but doesn't "turn on" (light, heat, etc.) when the X-10 is turned on.

— V. Alan Mode

A Your X-10 unit must be defective or poorly designed. At any rate, since the four watt lamp works, try a 0.1 μ F, 600V capacitor (Mouser part #75-MKT1813410635 should work) in parallel with the compact fluorescent lamp. The capacitor will not use any power and will help correct your power factor.

ELECTRIC CAR BATTERY CHARGER

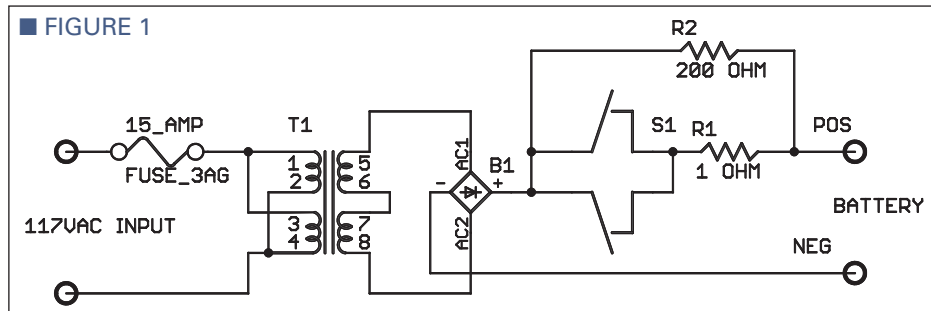
Q I am building an electric, plug-in car using 12 deep cycle 12 volt batteries for the 144 volts to drive the motor. Chargers for 144 volts are expensive so I would like to build my own if possible, that will run off 120 VAC so that I can recharge anywhere there is an outlet. Any ideas for a circuit would be welcome along with

cautions about how not to damage the batteries during charging and how to do it fairly efficiently. There are some "bad boy" chargers I have seen that are simply a transformer and rectifying bridge. Should these be used, for example?

— David Abineri

A The transformer/rectifier system works okay, you just need some way to limit the current. Most battery chargers have a circuit breaker if the current is too high, but I used a one ohm, 100 watt resistor to limit the current when the battery is in a low charge state (see Figure 1). The transformer is 1:1 when the primary windings are connected in parallel and the secondary windings are connected in series. The peak voltage is 165 volts which is needed to fully charge the 144 volt battery. The tolerance of components and line voltage is such that I would not recommend leaving the charger on the battery for more than a few days. So, there is a switch to disconnect the one ohm resistor, but leaving a 200 Ω in place to provide a trickle charge. The switch is double pole, single throw with the contacts connected in parallel. You can leave the trickle charge on indefinitely.

■ FIGURE 1



CIRCUIT TO PROTECT GPS UNIT

Q I have a little problem with my new Garmin C550 GPS navigation unit. The issue seems to be related to when

I start my truck. The voltage drop that occurs causes my GPS unit to fail to acquire any satellite signals. Let me illustrate this problem a bit clearer:

- Plug GPS unit into truck 12V lighter socket (unit is turned off).

- Start the truck.

- The GPS unit senses the presence of charging voltage and automatically turns itself on.

- GPS unit powers up to main screen, BUT fails to acquire any satellite signals.

- You can leave the GPS unit on indefinitely and it will never acquire the satellite signals.

To make the GPS unit work properly, here's what I have to do:

- Unplug the GPS from the lighter socket (unit is off).

- Start the truck.

- Plug the GPS unit into the 12V lighter socket (after the truck is already running).

- The GPS unit senses the presence of charging voltage and automatically turns itself on.

- GPS acquires the satellite signals fine and works correctly.

So, it seems the drop in battery

FIGURE 1 PARTS LIST

ITEM	DESCRIPTION	MOUSER P/N
■ Fuse Holder	Panel mount, 15 amp	441-FH001
■ Transformer T1	1:1, 1,500 VA	546-182T60
■ Bridge Rectifier	400 VAC, 25 amp	625-GPBC2506-E4
■ Toggle Switch	115 VAC, 30 amp	633-S21F-R0
■ Resistor, R1	1 ohm, 100 watt	588-L100J-1R0E
■ Resistor, R2	200 ohm, 5 watt	588-45F-200E

voltage that occurs during starting of my truck somehow causes the GPS unit to malfunction indefinitely until the unit is powered off then back on. I have a brand new battery in the truck, so I wouldn't think the voltage is going excessively low during starting. So, I'm looking for a little circuit I might be able to build into the lighter plug that will only pass voltage to the GPS unit when the battery is charging say, above 13.2 volts or so.

— Paul Bukowski

A I don't believe the voltage drop is the problem; the starter produces voltage transients that can exceed 60 volts; this has no doubt put the GPS into a protect mode. What you need is a transient suppressor circuit (see Figure 2). I simulated the circuit with a 60 volt input pulse (see Figure 3); the peak voltage out is 16.5 volts and the current through the zener is about one amp which is well within the ratings of a one watt zener, considering the short time. It is hard to find a 100 mH, one amp inductor.

The best I could find was a 16 mH common mode inductor rated at 2.6

amps. You could series the two windings to get 32 mH at 1.3 amps and series three of those to get 96 mH which is close enough. If you are tempted to try it with just one common mode choke, don't do it because the increased current will reduce the already low inductance, which will reduce the inductance even more. You can see where this will lead — to disaster! The inductor part number that I found was Mouser part #553-CMT908-V4.

P.S. I am glad you made me think about this because I built a six to 12 volt converter for my antique tractor, which failed right away. Now I know how to fix it (I already tried the lower inductance approach)!

HOW TO MONITOR SERIES CELLS

Q I have nine sub-C NiMH cells that make up the battery pack for a very lightweight electric assist system for a human powered vehicle. I'm normally drawing around 100 watts and the system weighs 4.2 pounds.

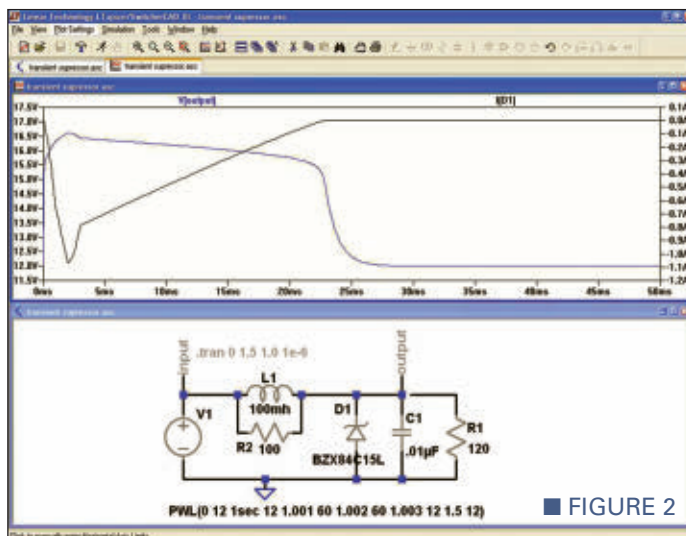


FIGURE 2

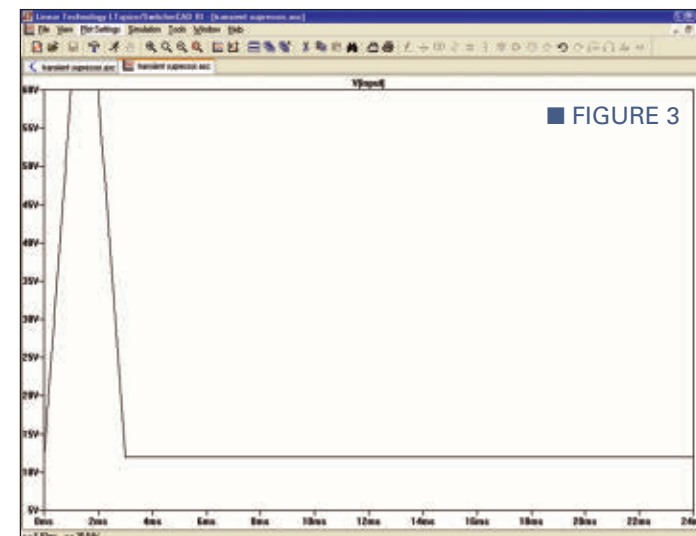
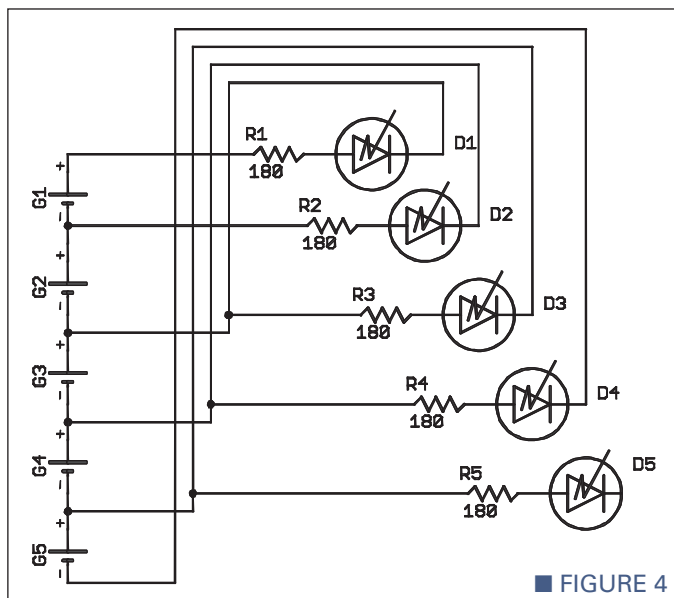


FIGURE 3

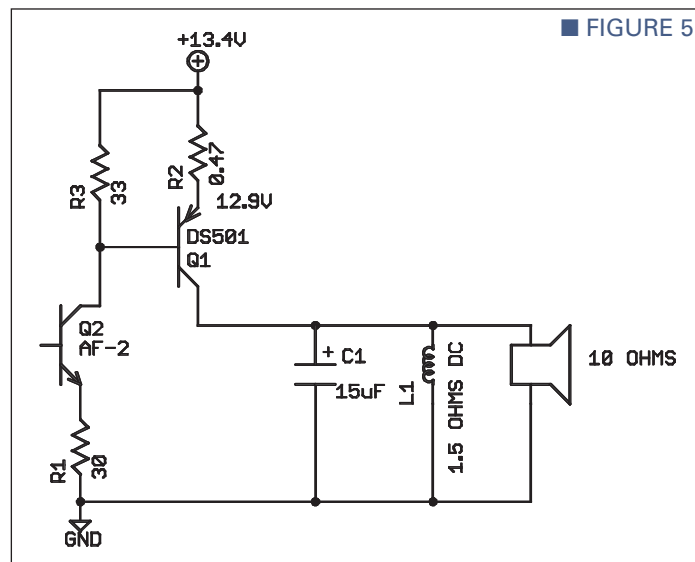


On discharge, quite often one or two weaker cells will discharge before the others. If power draw continues, those cells will go into negative voltage and will be damaged. To prevent this, I use a 10 volt zener diode and a LED across the pack. When the LED goes out, I do not draw any more power from the pack.

I already have a nine pin connector wired such that I can measure

voltage across each cell on the bench using a voltmeter (nine pins plus the outside case). This way, I can spot the weaker cells.

The above system works but is labor intensive and works on the bench, but is there a circuit that can measure across each cell that will point out which cells are weak during normal assist use? This way, I could monitor which cells are continuously weak and then change them to



voltage across each

increase pack mAh run time.

— John Tetz

A The NiMH cell voltage of 1.2 volts is too low to light even a red LED, so two cells are needed. You can use a bar graph which has 10 LEDs (you only need nine). I measured a bar graph (Mouser part #859-LTA-1000E) and found the voltage drop using 180 ohms in series with 2.4 volts to be 1.76 volts.

A partial circuit is shown in Figure 4. If D1 goes out, then either cell #1 or cell #2 is bad. If D2 is still lit, then cell #2 is good and cell #1 is bad. In general, if an inner cell is bad, two adjacent LEDs will be out and the lower cell will be the bad one; i.e., if D2 and D3 are out, cell #3 is bad.

AUDIO AMPLIFIERS

Q I have been an avid reader of *Nuts & Volts* for many years and sit here with my September '07 issue at hand. There is a topic under "Q and A" that speaks of Class A/B amplifiers. I have above novice level experience in electronics and would like to start on a new series of projects: building home and

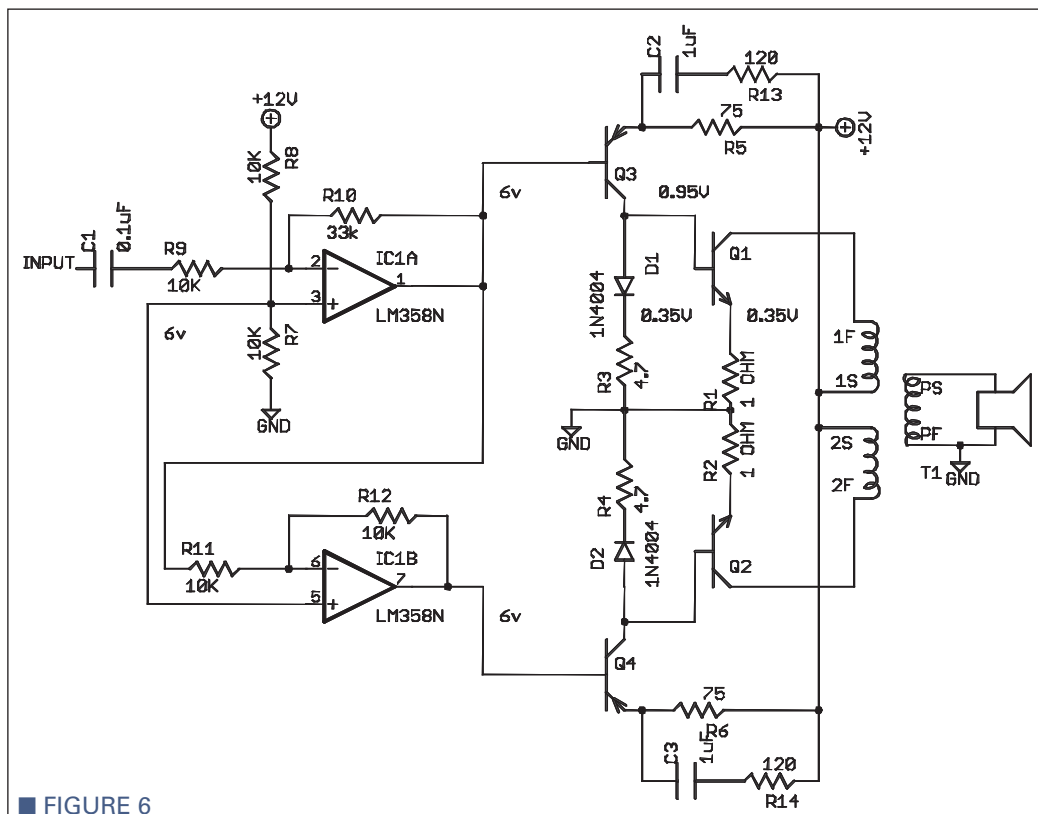


FIGURE 6

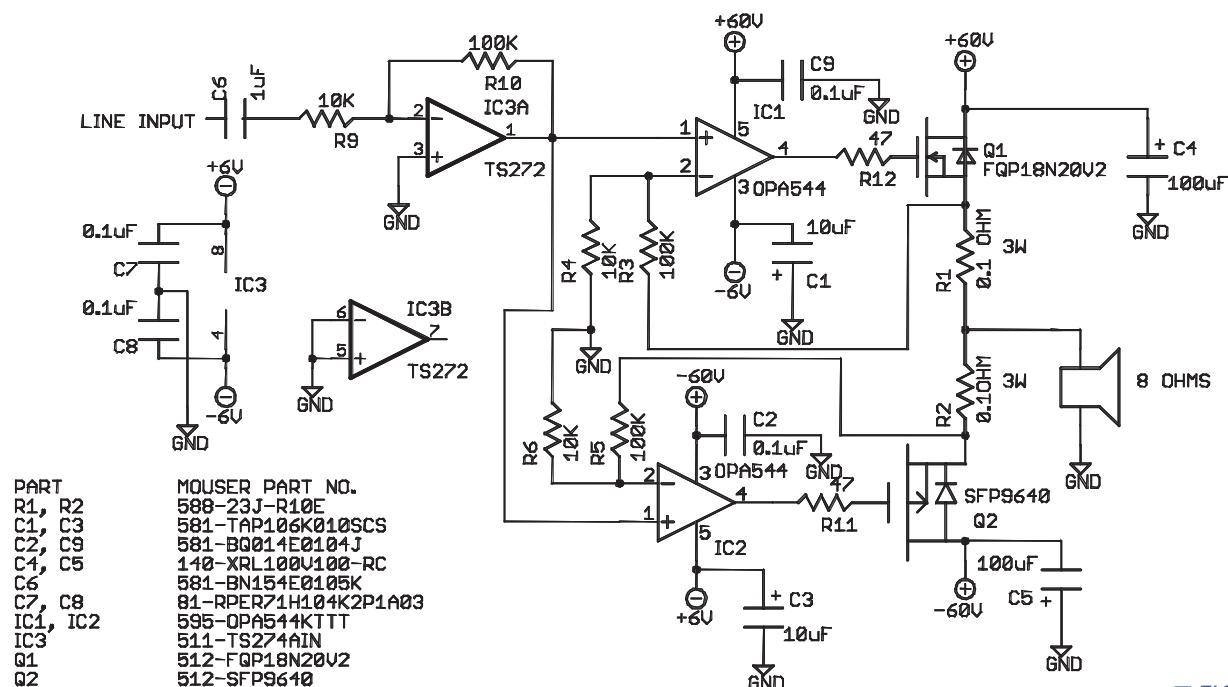


FIGURE 7

automotive audio amplifiers. I would like to know if you have any literature at hand that you could send to me detailing the different classes of amplifiers (A/B/D/Push Pull/etc.).

— Tyre Bernard Daniel

An audio amplifier consists of: a linear gain stage, power stage, and transformer. The linear gain stage may contain a volume control and bandwidth (tone) controls. Some amplifiers for band instruments have (yuck) “fuzz” and reverberation controls; I won’t consider those here. If the signal source is low level – like a turntable with magnetic pickup – a preamp is needed; I am not going to cover that either.

Consider the classes of amplifier: A, B, A/B, C, and D.

Class A could be a single transistor or two in push-pull (push-pull will be explained below). The defining parameter is that the current flows all the time in a more or less linear manner shown in Figure 5. This circuit was used for many years in Delco auto radios. The driver circuit was a module that was laser trimmed to provide a stable 0.7 volts DC to the DS501 power output transistor. If you calculate the emitter current of the DS501, it is about one amp average DC. The

inductor, L3, is needed to reduce the DC current through the speaker. This is not efficient or high fidelity, but a lot of

engineering went into making it cheap.

Figure 6 is a push-pull, class A power stage. The advantage of push-

MAILBAG

Dear Russell,

In the November ‘07 issue of *Nuts & Volts* under “Parallel Transistors,” you stated in your response to Daniel’s question that, in your experience, MOSFETs cannot be paralleled, while it’s one of their great benefits in comparison with other (bipolar) semiconductors.

All others have negative resistance/junction temperature curve (meaning when you heat NPN/PNP/IGBT, “resistance” goes down; the “hot” device draws even more current, and it goes on quickly till its soul (smoke) leaves its body. By the way, it proves that semiconductors work on smoke and when you let it out they stop working. MOSFETs are quite the opposite; junction temperature rises causing $R_{ds(on)}$ to go up; effectively compensating power distribution with paralleled devices.

What is commonly overlooked in such attempts is that when you parallel two (or more) MOSFETs, the input capacitance multiplies effectively, extending the on/off switching time.

Even if your driver circuit has been declared as 5,000 pF and one MOSFET as 1,500 pF, it does NOT mean that you can assume that, with no changes in driver circuit, you can drive two MOSFETs with 3,000 pF, as the on/off slope (time to switch) will significantly go up (will double). As the most dissipation comes from the time the unfortunate device is trying to move from one state to another, doubling the time can have disastrous effects; not because the MOSFETs cannot handle the current, but because you asked them to spend too much time in the linear region.

If you get time (and parts to spare), try to parallel MOSFETs while beefing up your driver circuit.

Miroslav Kisacanin

Response: What you say makes a lot of sense, but I had separate three amp drivers for each power MOSFET and still the transistors were exploding. I am still looking for an explanation of what I was doing wrong.



pull is that the nonlinearity of the transistors tends to cancel. It is still a power hog because both transistors are conducting all the time. Another advantage is that the magnetic field in the transformer due to bias current cancels; so a much smaller transformer can be used in push-pull than if a single transistor were used in a class A configuration.

A word about the transformer: It is not used to "match impedance." The output impedance of the

transistor is very high; you can't match it and get any power out. The transformer converts the speaker impedance to whatever is needed to get the power that is wanted. For example, if the power supply is 12 volts, the maximum peak-to-peak voltage at the transformer primary is 24 volts. If we want 10 watts to an eight ohm speaker, the primary impedance (AC resistance) must be: $R_{ac} = E^2/P = (24 \times 0.707)^2/10 = 29$ ohms.

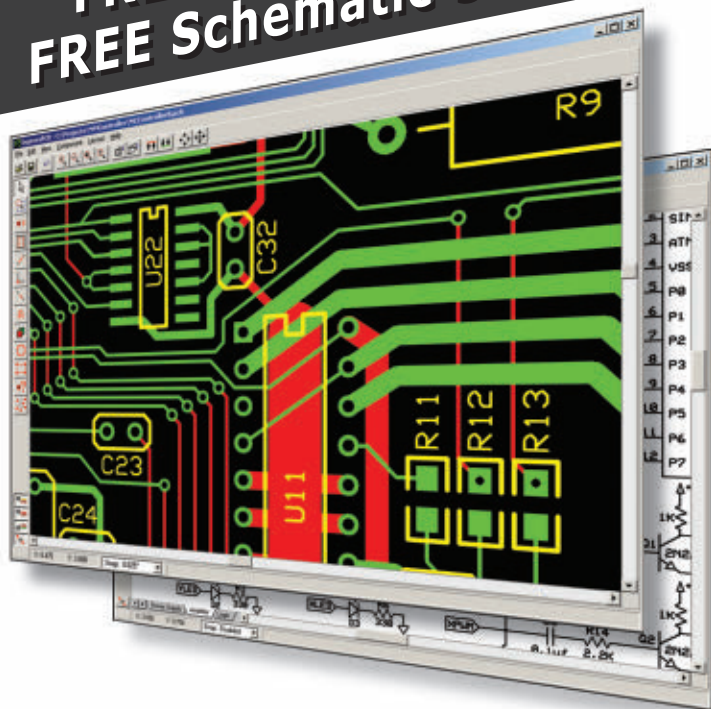
Notice that I converted peak-to-peak to RMS by multiplying by 0.707. The peak current in the primary is similarly computed: $I_p = 1.41 \times (P/R_{ac})^{0.5} = 0.7$ amp. In order for the current to flow all the time, the bias current for each transistor must be at least 0.35 amps.

In Figure 6, I made the emitter resistor of Q1 and Q2 equal to one ohm, therefore, the emitter voltage will be 0.35 volts with 0.35 amps bias current. I made the base resistors larger because not so much current is needed in the base circuit. To get 0.35 volts across 4.7 ohms, the current must be 74 mA. I set the base voltage of Q3 and Q4 at six volts with the voltage divider, R7 and R8, at IC1A input. That will allow three volts peak (six volts peak-to-peak) signal at Q3 and Q4 base. I only need 0.35 volts peak maximum at the Q1 emitter, so the gain from Q3 base to Q1 emitter is about 1/10 and the emitter resistance for Q3 and Q4 should be 47 ohms. R5 sets the bias so in order to parallel another resistor without upsetting the bias, I need a blocking capacitor. I calculated, using $X_c = 1/(2\pi FC)$, that 0.5 μF at 300 Hz is about one ohm, so I used 1 μF (bigger is better). And, I calculated using $R_p = R1 \times R2 / (R1 + R2)$ that 120 ohms is needed.

Figure 7 is a class A/B push-pull power stage. The only requirement for class A/B is that each transistor cuts off at some point in the AC waveform, but generally designers try to minimize the DC current when both transistors are conducting. For class B, there is a point in the AC waveform (near the zero crossing) when both transistors are off. In practical amplifiers, there is only a small difference between class B and A/B.

Figure 7 is a 100 watt amp. Designers have found that it is much cheaper to drive the speaker directly, so audio output transformers are generally not available. The design must prevent DC from flowing through the speaker because DC would offset the cone and cause distortion. The speaker could be AC coupled through a capacitor or DC coupled at zero volts average. You would only need one power supply using capacitor coupling, but a positive and negative supply is needed for DC coupling. In

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this case, I will use DC coupling because that will make it easier to feed back to the input for best linearity.

The input opamp, IC3A, is a pre-driver and buffer. When the input to IC1 goes below zero, the output of IC1 goes to -6 volts, cutting Q1 off. At the same time, IC2 output goes to -4 volts or whatever is needed to turn Q2 on. IC2 output can go negative as far as -55 volts. Assuming -4 volts V_{gs} for Q2, the voltage across the speaker and R2 is 51 volts. Similarly, the source of Q1 can go to +51 volts, so the peak-to-peak voltage is 102 volts. The sine wave power would be: $E^2/R = (.707 \times 51)^2 / 8.1 = 160.5$ watts. The 47 ohm resistor at the OPA544 op-amp is just to isolate the MOSFET input capacitance. I don't know if it is necessary, but it won't do any harm.

The output transistors, Q1 and Q2, will dissipate an equal amount of power, so you will need good heatsinking. One possibility is a heatsink designed for a solid-state relay (Mouser part #558-HE54), but a better idea is to put the circuit in a large aluminum box and use the box as the heatsink. Most of the resistors can be 1/4 watt; the parts list is in the schematic. This is a paper design, I have not built or simulated it, so if anyone builds it, please give me some feedback.

Class C is the case when both power transistors are off for an appreciable part of the cycle. It finds use in RF amplifiers, not audio amplifiers.

A class D amplifier is a switching circuit using PWM. I am not going to cover that here. **NV**

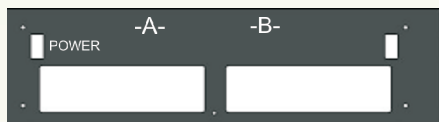


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Electronics make life better in innumerable ways, but the accompanying wires and cables often become a tangled mess that not only gets in the way, but also makes it difficult to figure out which cable belongs to which piece of equipment. John T. Lee, creator of the patent-pending Cordbone (www.cordbone.com), has devised an effective organizing device for tidying up the mess.



"The problem is that our USB cables, loudspeaker cables, power cords, and so on tend to be longer than we need, and that results in a tangle," explained Lee. "With the Cordbone, users can quickly and easily adjust the length so that there's no more excess. It works in the office, workshop, bathroom, with television or recording equipment — basically whenever you need to plug in something. And if your needs ever change, you can easily readjust the cord length to suit the situation."

The Cordbone is a simple, sturdy plastic device that allows users to quickly wind up a cable until it is at the desired length. Hooks at either end hold the cable in place while holes along the length keep the Cordbone light and allow users to loop smaller cables, such as adapter cords, as needed.

Lee is especially proud of the fact that the device, its materials, and even its packaging are 100 percent made in the United States. "Most businesses send their products to other countries for manufacturing and packaging, but with the Cordbone, it's all done here in the USA," he said.

The idea for the organizing tool

was born out of Lee's work at his own engineering company where miles of wiring and cords were a routine headache. He created homemade versions of the Cordbone in 2003 for use in his office, and friends, family, and associates began asking him to make some for them. A friend remarked on the way the hooks on either end made the device resemble a bone, and so the name of Cordbone came into being.

The Cordbone is available in packs of two, priced at \$6.99 per pack. Currently, the device is being sold online with minimum orders set at \$13.98 plus shipping fees. Orders of more than \$100 are shipped free, and purchases of 100 packs or more are eligible for special discounts.

For more information, contact:
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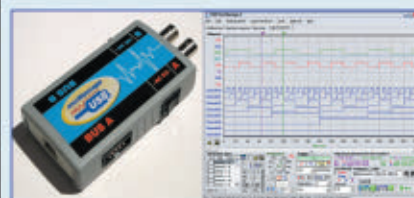
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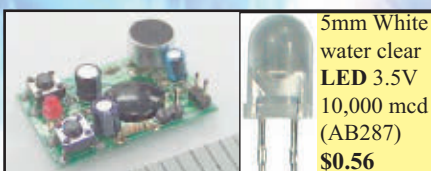
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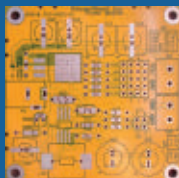
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Schmartie Award Winners

SchmartBoard — the developer of a new technology that has significantly simplified the creation of electronic circuits for hobbyists, education, and industry — has announced the winners of its second annual Schmartie Awards.

Schmartie Award participants, as a part of the SchmartDeveloper program, posted electronic circuit designs with a bill of materials that included the correct SchmartBoards (prototype boards) to the company's "SchmartDeveloper" website. The grand prize winner receives a \$1,000 cash prize, and SchmartBoard will

manufacture and market a Schmart Module product with their name on it.

Circuits and information about the winners and other applicants can be found at www.schmartdeveloper.org. Winners are:

- **Grand Prize** — Giannis Kedros of Thessaloniki, Greece — for his Serial to USB Module.
- **2nd Prize** — Charles Wenzel of Austin, TX — for his Low Jitter Quadrature Clock.
- **3rd Prize** — John Day of Toronto, ON Canada — for his USB-to-Serial and I²C Module.
- **Honorable Mention** — Daniel F. Ramirez of Amherst, NH — for his Schmart DC Motor Controller.

- **Honorable Mention** — Russell Pead of Littleton, MA — for his TTL Test Board.
- **Honorable Mention** — Robert Gatt of Port Fairy VIC, Australia — for his IR Proximity Detector.

The criteria used to choose the winners were originality, how well Schmart Board technology was used in the design, how useful the design is in the real world, and marketability of the design.

Co-sponsors of the contest were *Nuts & Volts Magazine*, *SERVO Magazine*, Cooper Tools, Link Instruments, Jameco Electronics, Mouser Electronics, Fry's Electronics, Circuit Specialists, Intellect Lab, Parallax, and RB Technology. **NV**

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- 3 x 2 in. supertwist LCD **\$119** TRM-425L
- 1200-9600 baud serial
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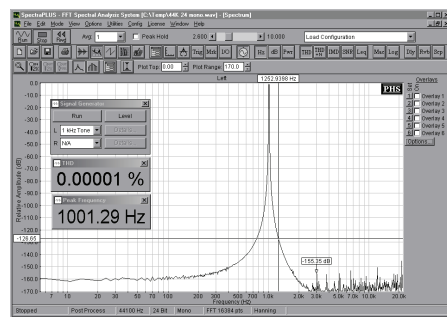
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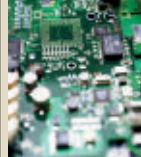
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■ THIS MONTH'S PROJECTS

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Coil Launcher	50

■ LEVEL RATING SYSTEM

To find out the level of difficulty for each of these projects, turn to our ratings for the answers.

- . . . Beginner Level
- . . . Intermediate Level
- . . . Advanced Level
- . . . Professional Level

I had planned on showing you how to add an LCD receiver satellite in this series, but before I do, I need to show you how to utilize the new Maxstream Series 2 XBee modules.

Maxstream no longer supports mesh networking utilizing the original XBee modules.

CONTROL YOUR WORLD

Build a Wireless Weather System: Final Fixes and Options

Mesh Network Options

This project series has been one of my most popular so I wanted to make sure you know your options in completing the different projects.

- OPTION 1: If you have not yet purchased your XBee modules, purchase the XBee Series 2 modules. There are only a few differences in the setup, of which I will be going into shortly.
- OPTION 2: If you have already

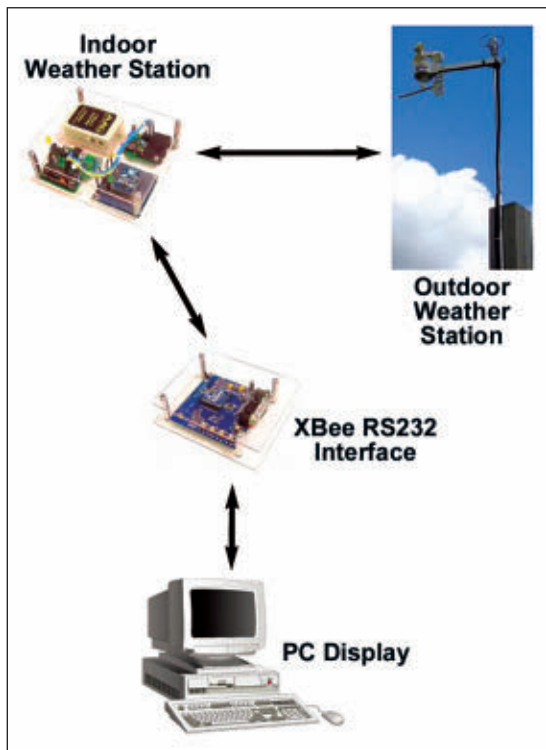
purchased Series 1 modules, you need to check to see if they are Rev A or Rev B. You can tell which type by looking at the sticker on the underside of the module. All Rev B modules have a REV-B on the sticker as shown in Figure 2.

If you have REV-B, you need to return the module. These modules cannot be used to create a mesh network. Contact your point of purchase first to see if you can return the modules. If they will not take the modules back, contact customer support at www.Maxstream.net.

If you have REV-A, you can contact customer support at www.Maxstream.net and they will send you the firmware files I utilized in the first part of this series.

- OPTION 3: The new series 2 modules are compatible with the series 1 development boards. If you purchased one of these boards or starter kits, you have the option of simply purchasing the individual Series 2 modules.

Maxstream has indicated to me that the Series 2 modules are mesh



■ FIGURE 1. System diagram showing the major players and the movement of data between them.



■ FIGURE 2

network only and do not support the 802.15.4 Point-to-Point protocol of the original modules. On the flip side, the original modules are 802.15.4 only and no longer support mesh networking.

I will be doing various point-to-point articles in the future so that you will be able to utilize the Series 1 modules.

I also wanted to let you know that at the time of this writing, the XBee Pro Series 2 module was not available. However, it should be available by the time this article goes to press. Once I get my hands on one, I will let you know how it works.

Series 2 Development Kit

All right, you know your options. I wanted to go into some detail on how to set up the new series 2 modules. Maxstream sells a development kit that's a perfect match for our weather station. Shown in Figure 3, the kit comes with five development boards. You get two USB and three RS-232 boards. The USB boards are actually RS-232 boards with USB-to-serial converters built in so that when the drivers are installed, they create new COM ports for our software to use.

The kit also comes with five XBee modules.



■ FIGURE 3

- One XB24-BCIT-004 – chip antenna
- Two XB24-BWIT-004 – wire antennas
- One XB24-BUIT-004 – UFL connector
- One XB24-BSIT-004 – SMA connector

The UFL connector is perfect for routing an antenna outside an enclosure. The development kit comes with a small UFL-to-SMA adapter cable that will connect this module to one of the included SMA antennas. The SMA connector based module can be connected directly to one of the included antennas. We will use both of these configurations for our weather station.

Configuration

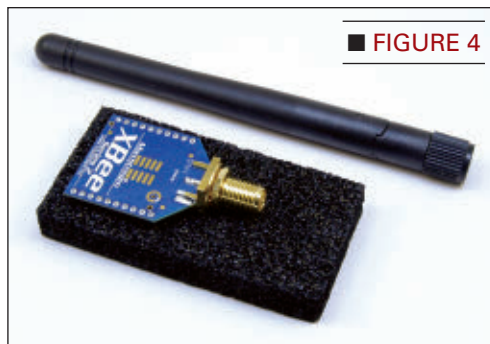
To get you started, I am going to create a coordinator and a router/end device so that we can get our weather network up and running. I will be using the development kit

for my examples. You can use any module or development board.

Coordinator Setup

Start by selecting the SMA based module and an SMA antenna as shown in Figure 4. Plug the module into one of the development boards and attach the antenna. I'm going to use one of the RS-232 development boards. I also recommend attaching the board to a plastic base in order to keep from shorting out if you happen to place it on top of something. I often also add a top base, as well for further protection as shown in Figure 5.

I am going to set this module up as a coordinator. Later, we will use the



■ FIGURE 4



■ FIGURE 5

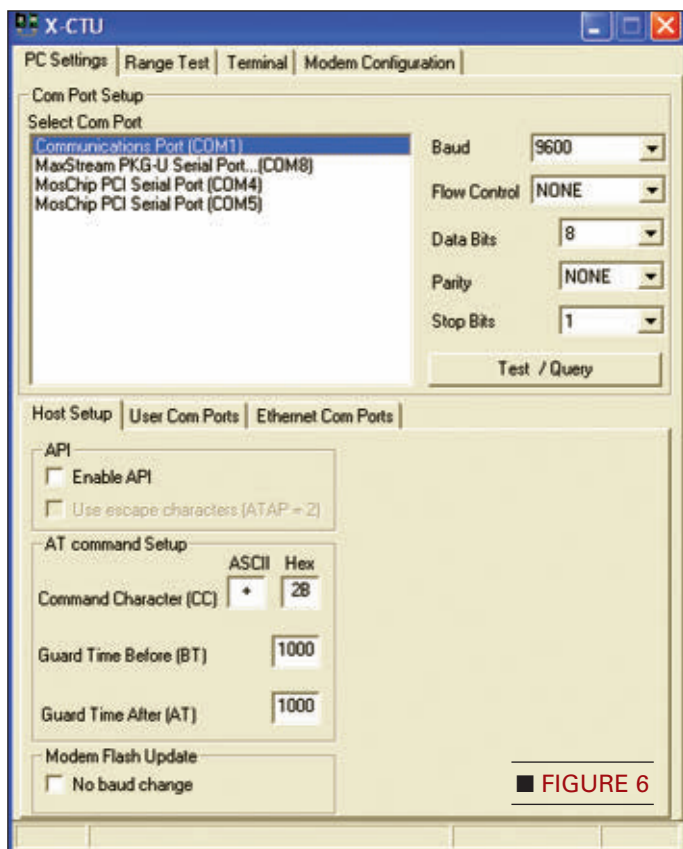


FIGURE 6

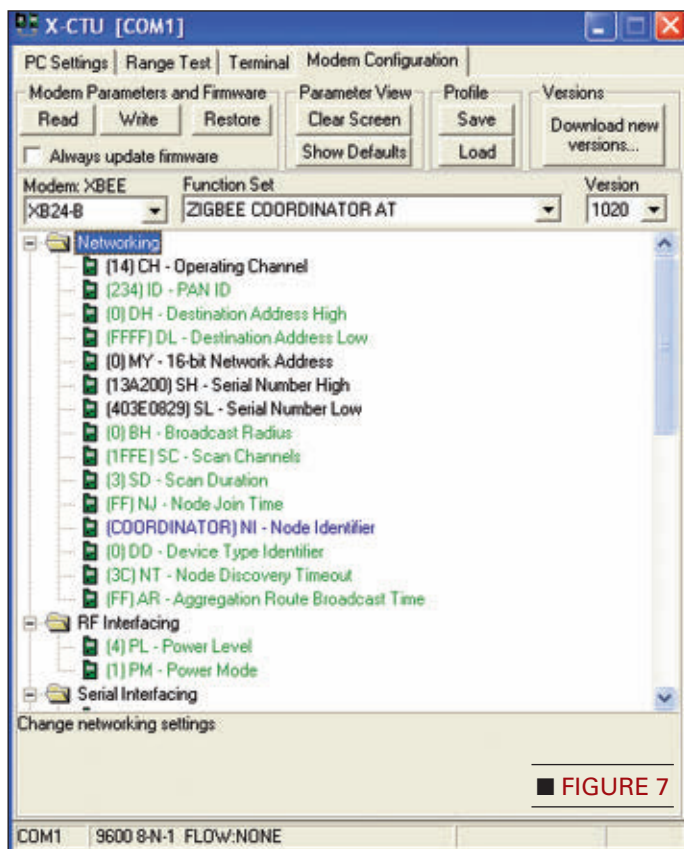


FIGURE 7

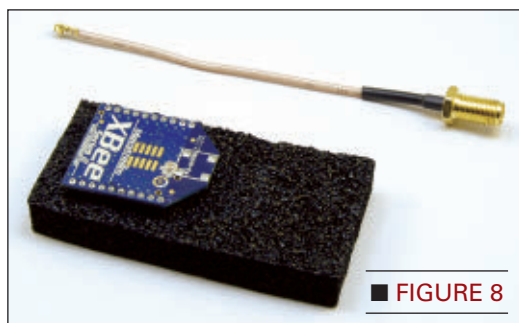


FIGURE 8

module in our coordinator satellite. Load up the X-CTU software and select the com port that is associated with the RS-232 development board as shown in Figure 6.

Apply power to the RS-232 development board (included in the kit). Select the Modem Configuration tab and hit the read button. Once the read is

complete, select the ZIGBEE COORDINATOR AT function set as shown in Figure 7 and hit the Write button.

Once the write is complete, hit the Read button. You need to set a few of the parameters. You can do this manually or use the XB2coord.pro file included in the downloads.

The fields that are changed include the following:

- PAN ID = 234
- Destination Address Low = FFFF
- Node Identifier = COORDINATOR
- Packetization Timeout = 25

Once the values are changed, hit the Write button. Make sure you label the module so you can keep track.

Router/End Device Setup

Take the UFL based module, the UFL-to-SMA adapter cable, and an SMA antenna as shown in Figure 8. Plug the module into one of the development boards and attach the antenna. In this case, I'm going to use one of the USB development boards.



FIGURE 9



FIGURE 10

Build a Wireless Weather System: Final Fixes and Options

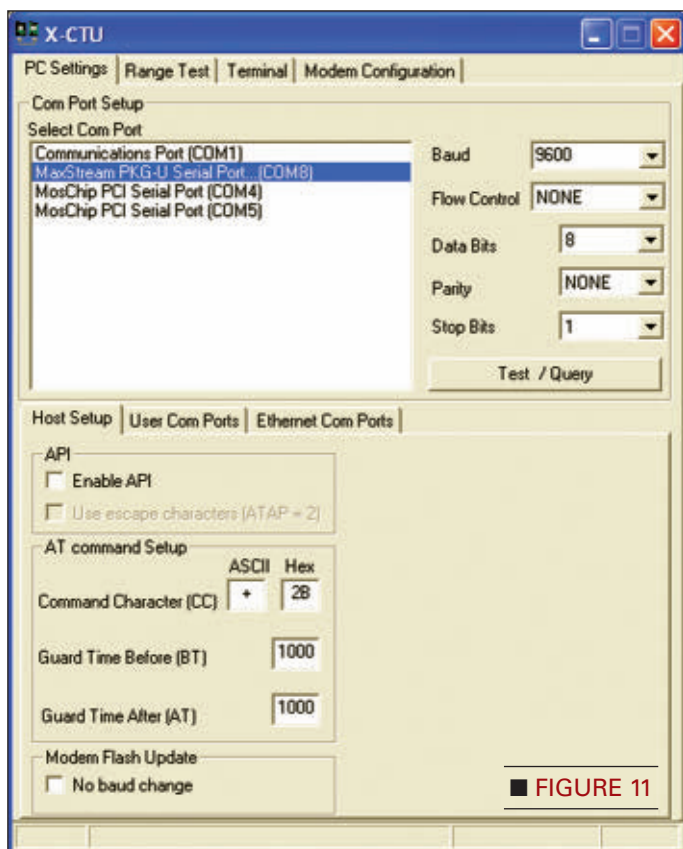


FIGURE 11

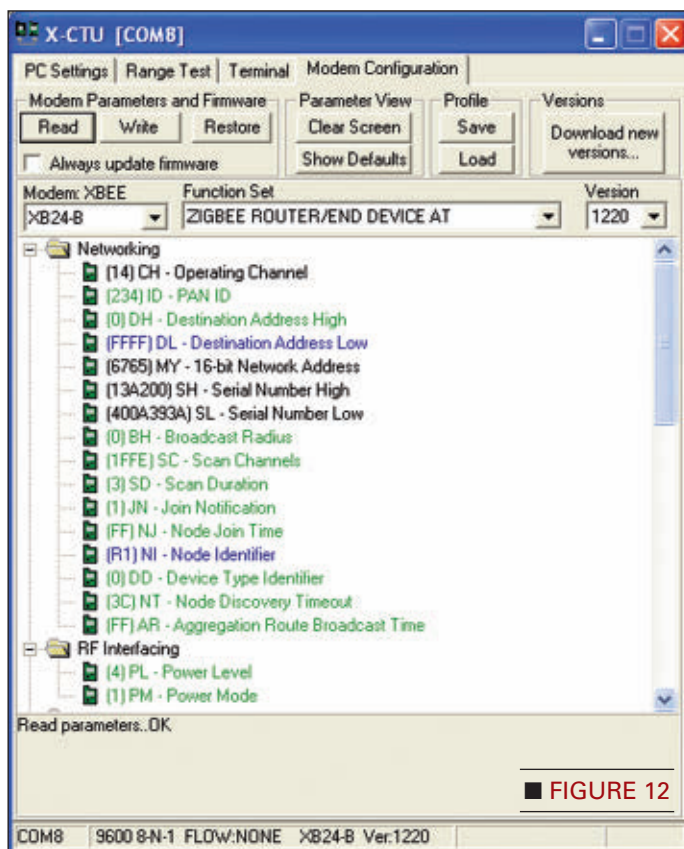


FIGURE 12

In order to use the SMA antenna with this module, you have two choices. First, you can mount the development board between two pieces of plastic and drill a hole to install the SMA side of the adapter cable as shown in Figure 9. You can also attach the small antenna clip (included with the kit) and route the adapter as shown in Figure 10. I also added some small rubber feet to this board in lieu of the plastic base. This particular module and development board will be used as my PC Weather Satellite.

Load up another copy of the X-CTU software and select the COM port that is associated with the USB development board as shown in Figure 11. The USB boards will have the name "MaxStream PKG-U Serial Port."

You won't need to apply power to this board. It gets its power from the USB port. Select the Modem Configuration tab and hit the Read button. Once the read is complete, select the ZIGBEE ROUTER/END DEVICE AT function set as shown in Figure 12 and hit the Write button.

Once the write is complete, hit the Read button. You need to set a few of the parameters. You can do this manually or use the XB2rout.pro file included in the downloads.

The fields that are changed include the following:

- PAN ID = 234
- Destination Address Low = FFFF
- Node Identifier = R1
- Packetization Timeout = 25

Once the values are changed, hit the Write button. Make sure you label the module so you can keep track.

Note that each router will need to have a different Node Identifier. I used R1-Rn in my network. It does not really matter what you use as long as they are different.

You may want to repeat the ROUTER/END DEVICE procedure just mentioned for all the remaining modules you are going to use in your network. You can utilize any of the

development boards for this.

Quick Test

At this point, you should be able to open the Terminal tab on each of the X-CTU software instances and type messages back and forth.

Indoor Weather Satellite Revisit

Once the new series 2 modules are configured, they are plug compatible in the weather satellites that I have described in the previous articles in this series. However, you may want to make

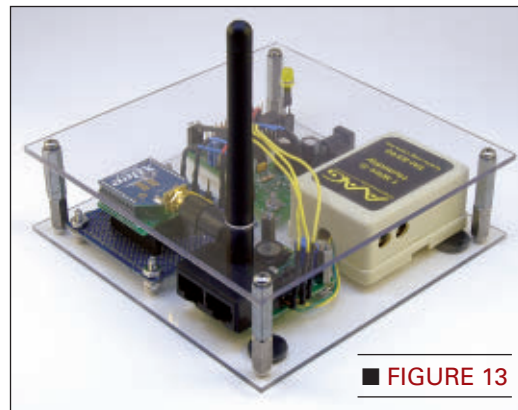
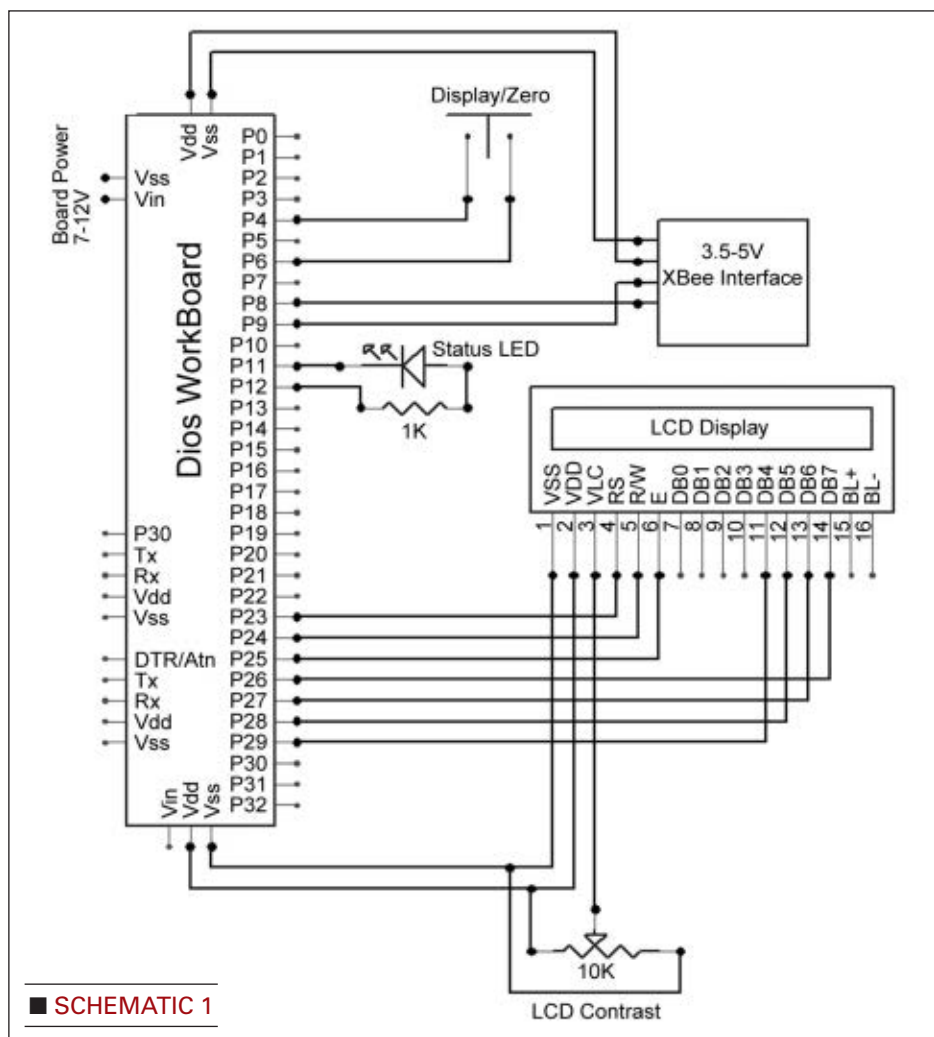


FIGURE 13



With this receiver, you will be able to create a small desktop display that will allow you to cycle through the various pieces of weather telemetry available on your weather network.

Let's start by looking at the circuit shown in Schematic 1, which shows the Dios Workboard. That's what I am going to use in this example, but you may also use the Dios Universal LCD carrier.

You will need the following components to complete this project. I will show you a complete source list later in this article.

- Dios Workboard Deluxe (Workboard Basic and DGLCD will also work)
- DiosPro 40-pin Chip
- Push Button
- LED
- 1K Resistor
- Character Based LCD (Sparkfun LCD-00255)
- Kronos Robotics 3.3-5V Interface Kit, SparkFun Xbee Breakout Board, and headers
- Xbee Module
- Free DiosPro Compiler

• **STEP 1:** Build the Kronos Robotics 3.3-5V interface kit and Xbee breakout board. If you are going to use this with a breadboard as I have done in Figure 14, make sure you install the five-pin header on the bottom of the board. If you will be mounting it in a more permanent enclosure, placing the header on top and using jumpers is a better choice.

Wire the interface according to Schematic 1. You don't need to attach the LCD at this time. Take the button and attach it to ports 4 and 6. As an option, attach an LED and resistor combination to ports 11 and 12.

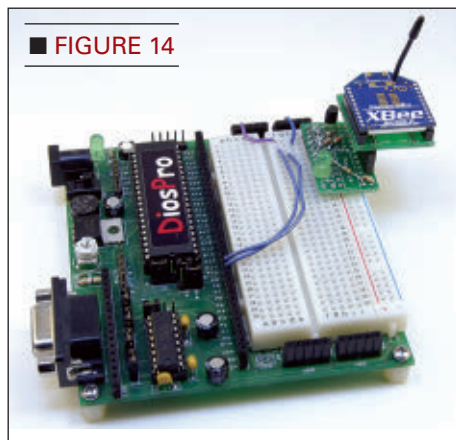
• **STEP 2:** Included in the downloads for this article is a program called WeatherReceiver.txt. Start the DiosPro compiler and load, then program the WeatherReceiver.txt file into the chip. Whenever the Xbee module receives any kind of signal, the green LED on the interface will light. When a valid weather packet start indicator is received, the optional LED on ports 11 and 12 will light. As weather packets

a few changes to accommodate the SMA antenna. Figure 13 shows how all that is needed is a small hole drilled in the upper base. Other than that, the electrical connections are the same.

Build the LCD Weather Receiver

Last time, I showed you how to use the protocol to create your own customizable satellites. Let's use that knowledge to create an LCD receiver.

■ FIGURE 14



LINKS

■ **Hobby Boards**
www.hobby-boards.com

■ **SparkFun Electronics**
www.sparkfun.com

■ **Kronos Robotics**
www.kronosrobotics.com/xcart/customer/home.php

■ **SchmartBoard**
www.schmartboard.com/index.asp?a=11&page=a_products

■ **Maxstream**
www.maxstream.net

Build a Wireless Weather System: Final Fixes and Options

are received, the readings will be displayed in the debug window as shown in Figure 15.

• **STEP 3:** Attach the LCD as shown in Figure 16 and load the program called LCDreceiver1.txt. The data will now appear on the LCD display. Use the button to cycle through the different displays. I have included another program called LCDreceiver2.txt. In this file, rain and lightning data is displayed.

By holding the button down until the status LED changes, you can zero out the rain or lightning totals. If you want to add these features to your weather station, you will have to add them to your outdoor satellite, as well. Some of the code from previous articles has this included; it's just a matter of adding the correct ROM for your 1Wire boards or chips.

You may also use the Dios Universal LCD carrier as shown in Figure 17. This has a much smaller footprint so you will need to mount the

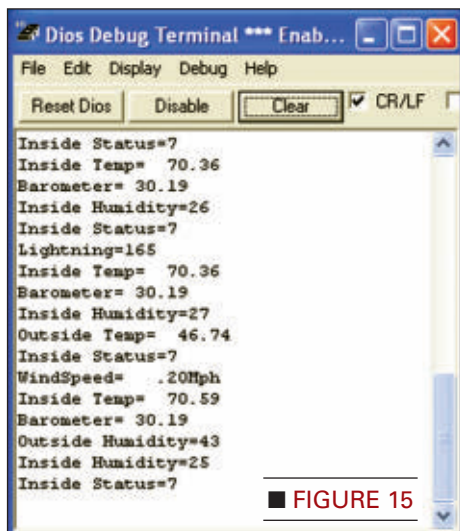


FIGURE 15

XBee interface on the bottom.

Final Thoughts

There is a ton of room for expanding the wireless weather station. It is even possible to utilize the system for controlling various aspects of your home. Some time in the future, I plan on writing a article where I have created an integrated thermostat that

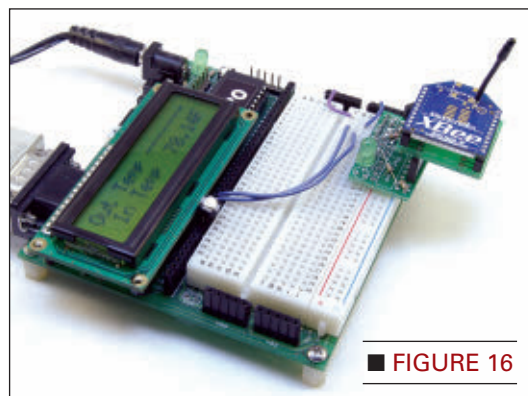


FIGURE 16

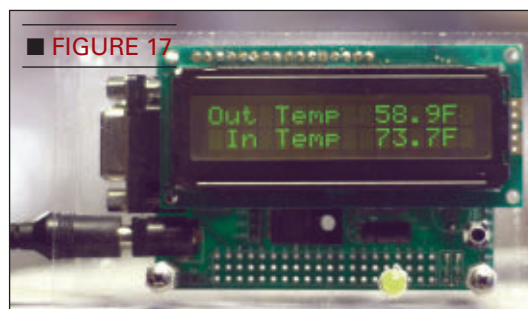


FIGURE 17

controls my home heating system.

Be sure to check for downloads and updates at www.kronosrobotics.com/Projects/wirelessweather.shtml. **NV**

PARTS LIST

The following is a breakdown of the sources for all the components needed for this part of the project.

MAXSTREAM

- Series 2 Development Kit

#XB24-BPDK

www.maxstream.net/products/xbee-series-2/dev-kit-zigbee.php

HOBBY BOARDS

- Lightning Detector

www.hobbyboards.com/catalog/product_info.php?cPath=22&products_id=65

SPARK FUN ELECTRONICS

- XBee Breakout Board (Used to build various interface boards)

www.sparkfun.com/commerce/product_info.php?products_id=8276

- 2 mm Connectors (You need two for each breakout board)

www.sparkfun.com/commerce/product_info.php?products_id=8272

- 2x16 Character LCD Black on Green

www.sparkfun.com/commerce/product_info.php?products_id=8272

[uct_info.php?products_id=255](http://www.kronosrobotics.com/xcart/customer/product.php?productid=255)

- 2x16 Character LCD White on Black

www.sparkfun.com/commerce/product_info.php?products_id=709

KRONOS ROBOTICS

- DiosPro 40 chip

www.kronosrobotics.com/xcart/customer/product.php?productid=16428

- Dios Workboard Deluxe

www.kronosrobotics.com/xcart/customer/product.php?productid=16452

- Dios Workboard Basic

www.kronosrobotics.com/xcart/customer/product.php?productid=16453

- Dios Universal LCD Carrier

www.kronosrobotics.com/xcart/customer/product.php?productid=16410

- 3.3V to 5V Interface Kit

www.kronosrobotics.com/xcart/customer/product.php?productid=16537

- 1K Resistors

www.kronosrobotics.com/xcart/customer/product.php?productid=16178

- Red LED

www.kronosrobotics.com/xcart/customer/product.php?productid=16234

- Push Button

www.kronosrobotics.com/xcart/customer/product.php?productid=16244

- 40 Pin Male Header

www.kronosrobotics.com/xcart/customer/product.php?productid=16290

- Free Dios Compiler (Includes 1Wire libraries)

www.kronosrobotics.com/downloads/DiosSetup.exe

SCHMARTBOARD

- Jumpers 5" Yellow

www.schmartboard.com/index.asp?a=11&id=42

- Jumpers 3" Red

www.schmartboard.com/index.asp?a=11&id=41



Although cell phones, global positioning system receivers, satellite television systems, and the AM/FM radio in your car perform completely different functions, the receivers used in these systems are all based on a concept first developed by the American electrical engineer Edwin Armstrong during the waning days of the first World War. Almost a century after its introduction — except for sophisticated approaches such as software radio that involve advanced digital signal processing techniques — Armstrong’s “superheterodyne” or “superhet” design reigns supreme in communications electronics.

Continue reading to learn how to build a simple superhet receiver that demonstrates Armstrong’s concepts.

A SIMPLE SUPERHET

Receiver Design Evolution

To understand the superhet’s superiority over previous designs or architectures, it is helpful to review a few of the difficulties of one receiver design that it replaced — that of the “Tuned Radio Frequency” or TRF receiver, shown in Figure 1. The TRF receiver came about from the common sense observation that since radio signals coming from the antenna are extremely weak, a more sensitive receiver might be obtained by amplifying the radio frequency (RF) signals immediately following the antenna. And given the poor performance of early vacuum tube amplifiers, if one stage provided insufficient gain, then cascading more stages should lead to a receiver that became progressively more sensitive (able to receive even weaker signals) and selective (able to select the desired signal and reject the others).

Unfortunately, these ideas

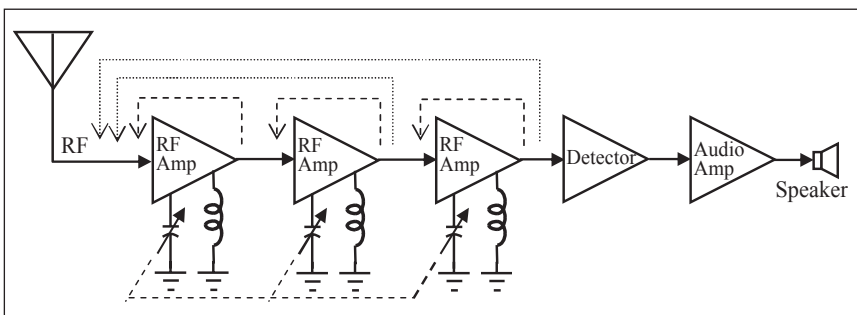
contain a number of troubling flaws that ultimately proved fatal to widespread application of this approach.

As far as increasing sensitivity goes, a problem immediately occurs because the radio frequency amplifiers necessary for each stage of the TRF receiver are inherently unstable. This is because in all electronic amplifiers — be they of the vacuum tube or transistor type — a small amount of capacitive coupling exists between the input and output of the device itself.

This intra-stage feedback is shown as the dashed line between the input and output of each stage in the figure. Several techniques, such as neutralization, may be employed to extend the frequency range of an individual TRF stage, but the difficulties of avoiding oscillation in tuneable, high-gain RF stages mount directly as the operating frequency increases.

Additionally, inter-stage feedback occurs when the output of one amplifier stage appears at the input of a preceding amplifier stage. The dotted lines in the figure show the multiple feedback paths that may exist in a TRF receiver with only a few stages. Either increasing the

■ FIGURE 1. Tuned Radio Frequency Receiver (TRF) block diagram showing intra-stage feedback (dashed line) and inter-stage feedback (dotted line).



gain of the individual stages or adding more stages to get more gain increases the inter-stage feedback, as well as the potential for oscillation.

Avoiding this problem requires great care to shield and decouple each stage from all of the others. Like intra-stage feedback, inter-stage feedback worsens as the operating frequency increases, compounding the difficulties of constructing sensitive, adjustable TRF receivers that will operate without oscillation over large frequency ranges.

Improving the selectivity of the TRF design introduces another set of problems. The most vexing one is related to a quirk in the parallel RLC tuned circuit, or “tank,” used to select the desired operating frequency. Unfortunately, the bandwidth of the parallel tank circuit is not constant with frequency, but increases approximately with the square root of the operating frequency.

For example, a TRF receiver tuned to 0.5 MHz might have a parallel RLC tank circuit designed to just receive a 10 kHz bandwidth signal. But the tank’s bandwidth increases to about 17 kHz — much wider than the desired signal — when the receiver is retuned to 1.5 MHz.

Another difficulty is associated with the mechanically linked tuned circuits that allow for simultaneous adjustment of the tuned circuits as the operating frequency changes. Any mechanical or electrical mismatch during tuning serves to decrease overall receiver selectivity.

Armstrong’s Design

The problems associated with the TRF receiver seem intractable, but Edwin Armstrong was a genius at thinking “out of the box” in order to solve complicated problems. Armstrong reasoned that if achieving a stable cascade of variable high-frequency amplifiers was a problem, he would avoid it. Armstrong built a cascade of fix-tuned amplifiers at a low frequency where a large amount of stable gain was easy to obtain. Then he preceded this amplifier cascade with a frequency translator or mixer stage in order to convert or “heterodyne” the desired signal to the new “intermediate frequency” or IF. Armstrong called this new receiver (which used heterodyning to translate signals to a fixed, lower intermediate frequency for reception) the “superheterodyne” receiver, as shown in the block diagram in Figure 2.

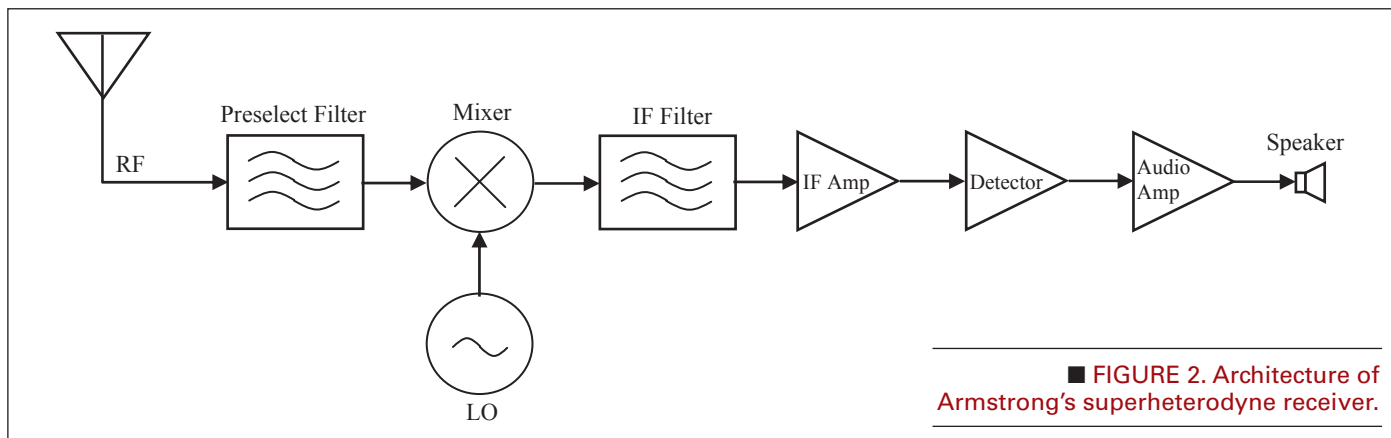
Designing an AM superhet receiver for the commercial broadcast band is a good way to better understand the operation of Armstrong’s superheterodyne receiver. The AM broadcast band contains 117 10 kHz-wide channels spaced between 530–1,700 kHz. In order to generate a fixed IF of 455 kHz (the standard IF for the AM broadcast band since the 1930s), the local oscillator (LO) must be able to generate a signal that tracks exactly 455 kHz above the incoming signal, or between 985–2,155 kHz.

The mixer takes these two signals, the RF and the LO, and outputs the

difference frequency, $LO - RF$, to the IF amplifier. The fix-tuned IF amplifier selects the incoming 10 kHz wide signal while rejecting any signals present in adjacent channels above and below 455 kHz. For example, in order to receive a 1,000 kHz RF signal, the LO must generate a 1,455 kHz signal in order to translate the incoming signal to the 455 kHz IF. After amplification, the IF signal is then demodulated to detect the desired audio signal from the radio frequency carrier, amplified by the audio amplifier, and then applied to headphones or a speaker to convert the electrical signal into an acoustic one so you again can hear the broadcast (see Figure 2).

There is another signal that can produce a 455 kHz output from the mixer when the LO is tuned to 1,455 kHz. That signal is called the “image frequency,” and it is located at $LO + IF$ or 1,910 kHz. Note that because the image frequency produces the same 455 kHz IF when applied to the mixer as the desired signal, it is necessary to eliminate the image frequency before it reaches the mixer. This is done with a parallel-tuned tank circuit, also known as a preselector, that follows the antenna.

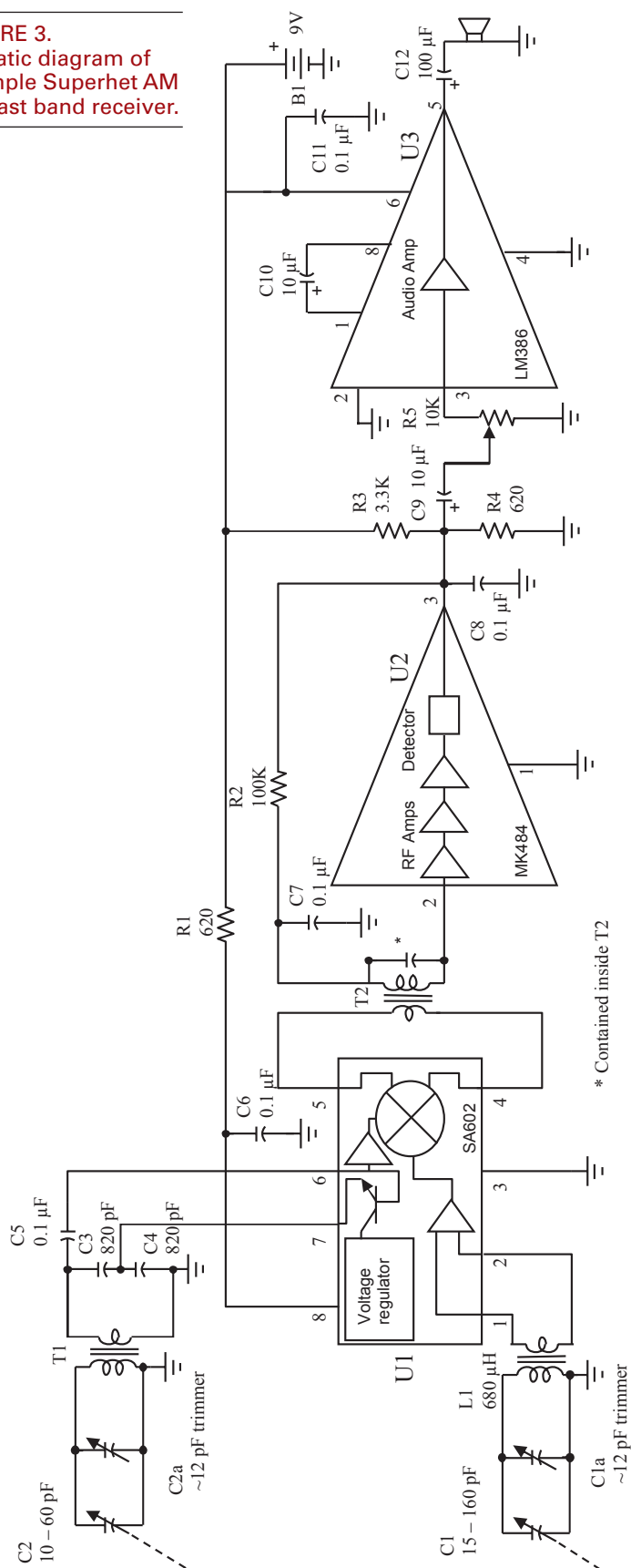
It is important to realize that in the superhet receiver, the requirements on the preselector are greatly diminished compared to the tuned circuits in the TRF receiver. In the superhet, the preselector only needs to select one of two signals that are separated by 910 kHz — a relatively simple task — while the tuned circuits



■ FIGURE 2. Architecture of Armstrong’s superheterodyne receiver.



■ **FIGURE 3.**
Schematic diagram of
the Simple Superhet AM
broadcast band receiver.



in the TRF are required to separate signals as close as 10 kHz across the entire frequency range of the receiver.

Circuit Description

Now that we understand the basic operation of Armstrong's superhet receiver, we are ready to build a simple radio that incorporates all of these concepts. The schematic of a receiver I call the Simple Superhet is shown in Figure 3. I chose this name because I believe the circuit is just about the simplest, fully functional superheterodyne receiver one can construct with just a handful of parts.

Many electronics experimenters will be familiar with the three ICs used in this design as they are commonly found in many homebrew receiver projects. Let's take a look at them one at a time before we see how they work together in the Simple Superhet.

The SA602AN (which is a pin-for-pin equivalent to the NE602N originally produced by Signetics) is an eight-lead dual in-line package (DIP) intended for low-power, high performance communications systems. It contains an onboard oscillator transistor that requires only a few passive components to implement the LO function. The IC also contains a double-balanced mixer that produces the IF output by combining the internally generated LO with the input RF signal.

Amplification at the IF and detection of the audio signal is handled by the MK484 (originally produced as the ZN414Z by GEC Plessey). This IC contains a 10 transistor TRF receiver circuit packaged in a three-pin TO-92 package. The MK484 implements a TRF receiver by cascading three high-gain RF amplifiers followed by a transistor detector.

This IC provides a very high power gain of 72 dB using a supply voltage of only about 1.5V! Although the IC functions from 150 kHz to 3,000 kHz, manufacturer's performance curves show that maximum gain for small input signals occurs very near the 455 kHz IF — a perfect match for the Simple Superhet!

The final IC — also an eight-lead

DIP — is the LM386N-1 low voltage audio power amplifier. This IC is designed for use in low voltage consumer applications and can provide gains up to 46 dB. This amplifier provides sufficient output power to drive a small speaker when the receiver is tuned to local stations.

Construction

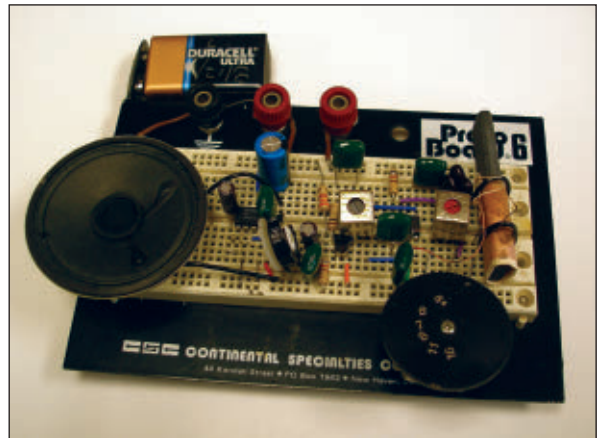
Now that we've introduced the three ICs, let's return to Figure 3 and see how to combine them to form the Simple Superhet. The primary of the ferrite antenna loopstick, L1, and the variable capacitor, C1, form a parallel tank circuit that "preselects" the desired signal, while attenuating any image signal that might also be present. The antenna loopstick also converts the electromagnetic field of incoming radio waves into a small RF voltage that is applied through the loopstick's secondary winding to the input of the double-balanced mixer, pins 1 and 2 of U1.

Variable capacitor C2, transformer T1 (red can), and capacitors C3–C5, along with the oscillator transistor internal to the SA602 form a Colpitts oscillator that serves as a tuneable LO for the Simple Superhet. The Colpitts oscillator creates oscillations by feeding back the output signal from the emitter of the oscillator transistor (pin 7) to the base of the oscillator transistor (pin 6) through the capacitive voltage divider formed by C3 and C4.

Note that the primary of the red can (side with three pins) is connected to C2, while the secondary (side with two pins) is connected to C3 and C4. R1 and C6 form a decoupling network that keeps RF and LO signals off of the power supply line, while also limiting the supply voltage for the SA602 to less than eight volts as required for this IC. The output of the SA602 is the desired IF signal which appears as a balanced output signal across pins 4 and 5.

Transformer T2 (yellow can) and the MK484 IC form the heart of the IF amplifier. It is important to observe that in this application the IF transformer is turned around "backwards" in order to convert the balanced output of the

■ **FIGURE 4. Prototype of the Simple Superhet receiver. Do not force the IF transformer into the board as the plastic case may split. Instead, solder a short wire extension onto each pin to insert into the corresponding hole to complete the connection.**



mixer into a high impedance, singled-ended output to drive the MK484. Note that in this case the primary of the yellow can (side with three pins) is connected to pin 2 of the MK484, while the secondary (side with two pins) is connected between pins 4 and 5 of the SA602. The single IF filter is extremely selective because the equivalent load resistance on the primary of T2 is very large.

Continuing with the operation of the MK484, resistors R3 and R4 form a voltage divider that reduces the 9V supply voltage to approximately 1.6V necessary to power the IC. Resistor R2 and capacitor C7 provide decoupled bias to the IC's input, while capacitor C8 shorts any RF present at the IC's output to ground.

The operation of the LM386 audio amplifier is very straightforward. Potentiometer R5 attenuates the audio signal to provide the user with a volume control. Capacitor C10 maximizes the amplifier's audio gain, capacitor C11 decouples the supply voltage, and capacitor C12 blocks DC current from the speaker coil.

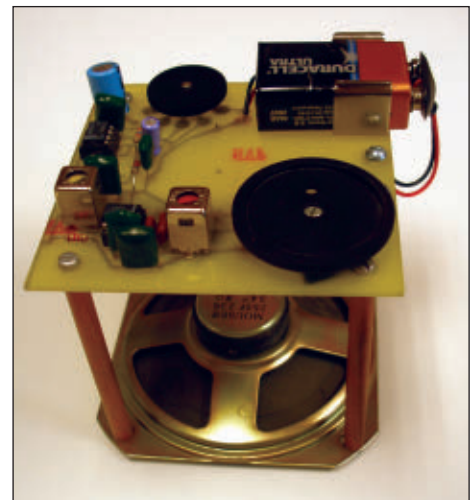
A good strategy for receiver construction is to start at the speaker and build towards the antenna. This allows the builder to aurally verify circuit operation as work progresses. Additionally, a very fast way to construct this circuit is by plugging the components into a proto board as

shown in Figure 4. Once circuit operation is verified, it is straightforward to construct the circuit on something more permanent, such as a PC board construction shown in Figure 5.

Begin constructing the audio amplifier by wiring in the LM386 IC, speaker, R5, and C9–C12. Apply power to the IC along with an audio tone from a signal generator to the free end of C9. You should be able to hear a healthy tone at the speaker with volume adjustment provided by R5. Next add the MK484, R2–R4, C7–C8, and the yellow IF can. Connect a low level 455 kHz tone modulated signal to the secondary of the IF can, apply power to the circuit, and the demodulated tone should be plainly audible on the speaker.

Adjust the screw on the IF transformer to obtain maximum volume with the modulated 455 kHz signal. If you don't have a 455 kHz signal

■ **FIGURE 5. An example of a PCB implementation of the superhet receiver with a 3-1/2" speaker used as the base. The PCB is supported above the speaker by 3" long wooden dowels. The loopstick antenna (not visible) is mounted underneath the PCB using a small metal bracket.**



PARTS LIST

ITEM DESCRIPTION

Resistors (1/4 watt)

- ☐ R1, R4 620 Ω
- ☐ R2 100K
- ☐ R3 3.3K
- ☐ R5 10K potentiometer

Capacitors (25 volts or higher)

- ☐ C1-C2 Two-section, ganged variable capacitor with trimmers. Antenna section, 15-160 pF; oscillator section, 10-60 pF.
- ☐ C3, C4 820 pF mica or Hi-Q ceramic
- ☐ C5, C6, C7 0.1 μ F monolithic ceramic
- ☐ C8, C11 0.1 μ F monolithic ceramic
- ☐ C9, C10 10 μ F electrolytic
- ☐ C12 100 μ F electrolytic

Inductors

- ☐ L1 680 μ H ferrite loopstick antenna
- ☐ T1 AM BC band local oscillator transformer (red can)
- ☐ T2 455 kHz intermediate frequency transformer (yellow can)

Semiconductors

- ☐ U1 SA602AN (or NE602N) LO/mixer
- ☐ U2 MK484 (or ZN414Z) TRF receiver/detector
- ☐ U3 LM386N-1 audio amp

Miscellaneous

- ☐ B1 9V battery and snap connector
- ☐ Knobs
- ☐ 8 Ω speaker

generator available, center the screw near the mid-range position and proceed. Complete the Simple Superhet by wiring in the SA602 along with the remaining components.

counter to pin 4 or 5 of the SA602 to monitor the oscillator frequency.

Apply power to your circuit and rotate the variable capacitor C1-C2 fully counter-clockwise (CCW). Then adjust

DIGGING DEEPER

- Superhetrodyne receiver design and operation is discussed in great detail in Chapter 4 of Tomasi, Wayne, *Electronic Communications Systems Fundamentals Through Advanced*, 5th Edition, Prentice Hall Career & Technology, Englewood Cliffs, NJ 2003.

- For an interesting discussion of why tuned-input/tuned-output amplifiers are so difficult to stabilize see Young, Paul H., *Electronic Communication Techniques*, 5th Edition, Prentice Hall, Upper Saddle River, NJ 2004.

- The operation of the SA602AN oscillator and mixer are discussed in Chapters 11 and 12 respectively of Rutledge, David B., *The Electronics of Radio*, Cambridge University Press, Cambridge, UK 1999.

Testing and Calibration

The radio is finished, but it is necessary to properly align the RF and LO circuits before it will receive any stations. With a small non-metallic screwdriver, unmesh the LO and RF trimmer capacitors C1a and C2a that are found on the back of the plastic-cased variable capacitor C1-C2. Next, tune an AM/shortwave receiver to 985 kHz and place it next to your circuit, or capacitively couple a frequency

the screw on the LO transformer T1 (red can) to spot the signal from the oscillator at 985 kHz. Rotate the variable capacitor fully clockwise (CW) and then tune trimmer capacitor C2a until you can spot the signal at 2,155 kHz using the monitor receiver or frequency counter.

Repeat the above steps once or twice adjusting T1 at the low frequency end and C2a at the high frequency end. You have successfully aligned the LO stage when full CCW and CW rotation of the variable capacitor produces signals between 985 kHz and 2,155 kHz, respectively. (Note: Stray capacitance, particularly if you use proto board construction, may limit the frequency spread you can achieve to less than the full range).

Align the RF preselector by tuning the variable capacitor to a station near the lower end of the AM band, or loosely couple a signal from a signal generator into the ferrite antenna using a small

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loop of wire. Very slowly slide the ferrite bar in and out of the loopstick antenna until the loudest audio signal is produced. Then secure the ferrite bar in place with a small wedge of paper.

Retune the radio to a station (or the signal generator, if used) near the upper end of the AM band. This time, very carefully adjust trimmer capacitor C1a until the loudest audio is produced. Repeat this procedure, adjusting the ferrite bar at the low frequency end and the trimmer capacitor at the high frequency end, to maximize volume for stations located at both ends of the AM band. This completes construction, testing, and alignment of the Simple Superhet receiver.

From Here

Here are some other things you can try on your own:

- Try increasing or decreasing the number of turns on the secondary of the ferrite antenna bar to improve receiver sensitivity. If your loopstick antenna did not come with a secondary coil, you can wind your own secondary coil using about a dozen turns of fine magnet wire over the existing primary turns.

- Substitute the "white can" or "black can" for the yellow can IF transformer to see how sensitivity and/or selectivity change.

- Increase or decrease R3 one or two

standard resistor values to see how it affects the gain and stability of the MK484 IF amplifier. (Note: Keep the voltage at pin 3 of the MK484 below 1.8V to avoid destroying the IC!)

- Advanced experimenters may modify the basic design to build a superhet receiver for other interesting frequency bands such as Citizen's Band or WWV. Proceed by constructing a crystal oscilla-

tor or Phase Locked Loop (PLL) frequency synthesizer for the LO, as well as modifying the preselector to properly receive signals in the desired frequency range.

I hope you have as much fun building, using, and modifying your Simple Superhet receiver as I have had with mine! You may contact me with any questions or comments at john.post@erau.edu. **NV**

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Datasheets for ICs
www.rapidonline.com/resources/docs/82-1026.pdf

www.datasheetcatalog.com/datasheets_pdf/S/A/6/0/SA602AN_01.shtml

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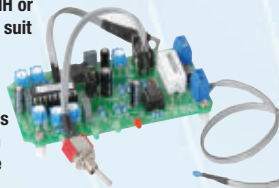
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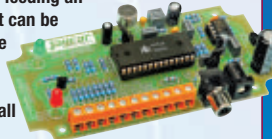
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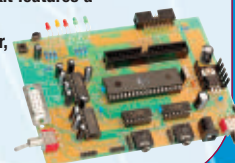
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Most conventional firearms operate by the action of expanding gasses forcing a projectile out of a barrel at high speed. The propulsion for these systems is the detonation of gunpowder that causes an explosion behind a projectile positioned in a tube (barrel) that is closed at one end (the breech). Systems that operate on gunpowder are extremely loud and leave residue in the barrel and action making them prone to malfunction and requiring considerable cleaning efforts for continued use. With new research and innovation in high-tech electronic weapons systems,

gunpowder may soon become a thing of the past.

ELECTROMAGNETIC COIL LAUNCHER PROJECT

Make way for the electromagnetic coil launchers! These devices substitute electromagnetic (EM) propulsion for gunpowder with nearly equivalent results in speed and kinetic energy. What better way to get acquainted with this futuristic technology than to build your own electromagnetic launcher!

The objective of this project is to design and construct a portable, self-contained electromagnetic coil launcher. A coil launcher is a type of rifle that uses an electromagnetic accelerator coil or a series of coils to accelerate a metallic projectile. The

Strategic Defense Initiative of the 1980s — often referred to as “Star Wars” — was one of the first defense projects to realize the dream of futuristic electronic weapon systems development. A fully functional rail gun was developed for this program although it was never deployed in space.

Coil Launcher Principles

Coil launchers use a strong magnetic field to accelerate ferromagnetic projectiles. The projectiles used in coil and rail launchers are often referred to as armatures. A large electric current is switched from a fast discharge storage device (usually a capacitor bank) into a coil of wire wrapped around a barrel to produce the strong magnetic field required for the rapid acceleration of the metallic projectile.

The projectile is situated at one end of the coil and is pulled to its center by magnetic induction. When the current is switched off, the projectile travels forward down the barrel, exits the launcher and moves towards the intended target. The force applied to the armature is proportional to the change in inductance of the coil with respect to the

CAUTION

The information contained in this article is dangerous and potentially life threatening. Use extreme caution when experimenting with high voltage and capacitor discharge circuits. If you are not experienced in the fabrication of such devices, then do not attempt to build this project. Always short out the capacitor bank when working with it or the circuit. Regular firearm handling precautions should be taken. Always wear eye protection. The author and the publisher accept no liability and will not be held responsible for any injury or damages caused by the construction, use, or misuse of this device.

change in position of the armature and the current flowing through the coil.

The force applied to the armature will always move it in a direction that increases the coil inductance. These systems are very quiet when projectiles are fired at velocities lower than the speed of sound, are clean, and require little maintenance. More advanced coil launcher designs incorporate a number of accelerator coils switched in sequence as the projectile moves down the barrel.

The multiple coil design is intended to maximize projectile velocity. The major problem with electromagnetic weapons at the moment is the huge amount of energy lost when converting the electrical energy into kinetic energy.

Project Overview

This article will describe the general construction of the electromagnetic coil launcher shown in Figure 1. The EM-15 coil launcher is a hand-held, battery powered (12 VDC) rifle that is capable of launching a .30 caliber metallic projectile at adjustable velocities. This is a great project to explore a number of analog electronics concepts.

The electronic circuit consists of a voltage step-up transformer converter, a Cockcroft-Walton voltage multiplier cascade, a capacitor energy storage bank, a voltage comparator to set the charge voltage on the capacitor bank, an SCR switching section, and an accelerator coil. Other components of the launcher are the barrel, breech loading mechanism, battery supply, control panel, display, projectile, pistol grip with trigger assembly, and an aluminum stock that contains all of the components.

The design, construction, and operation of the transformer used in this project is explained step-by-step since it is a key component that is often overlooked in articles and books concerning high voltage. When the launcher is completed, it will be calibrated and fired. Be sure to watch the video of it in action at

www.thinkbotics.com/military.htm

Circuit Theory

The EM-15 coil launcher schematic diagram is shown in Figure 2. The inverter section of the circuit produces a high frequency, high voltage using an oscillator configuration consisting of transformer T1 being switched on and off by transistor Q1. When power is applied to the circuit by switch S1, resistor R2 initiates transistor Q1 to turn on and conduct a current of 12 volts DC through the primary winding (10 turns) of the transformer. The current passing through the primary winding induces a magnetic field in the iron core causing it to produce a current in the secondary (500 turns) and feedback (eight turns) windings. The feedback voltage holds transistor Q1 on as the current flows through resistor R1 and capacitor C2. Resistor R1 and capacitor C2 control the base current and operating frequency of the oscillator.

When the core of the transformer saturates, the induced base voltage goes to zero and turns the transistor off. The magnetic field in the ferrite core then collapses and produces 600 VAC in the secondary windings of the transformer. At this point, the transistor turns on again and the cycle repeats.

The high voltage AC output from the secondary winding of the transformer is doubled and rectified to 1,200 VDC by a Cockcroft-Walton voltage multiplier made up of diodes D1, D2, and capacitors C3, C4. The DC output voltage from the voltage multiplier charges the capacitor bank through the accelerator coil L1, to a voltage that is determined by IC1, a 741 operational amplifier configured as a comparator.

The Cockcroft-Walton voltage multiplier is an interesting device that was named after Douglas Cockcroft and Ernest Walton. In 1932, the scientists used this voltage multiplier cascade design to power a particle accelerator and perform the first

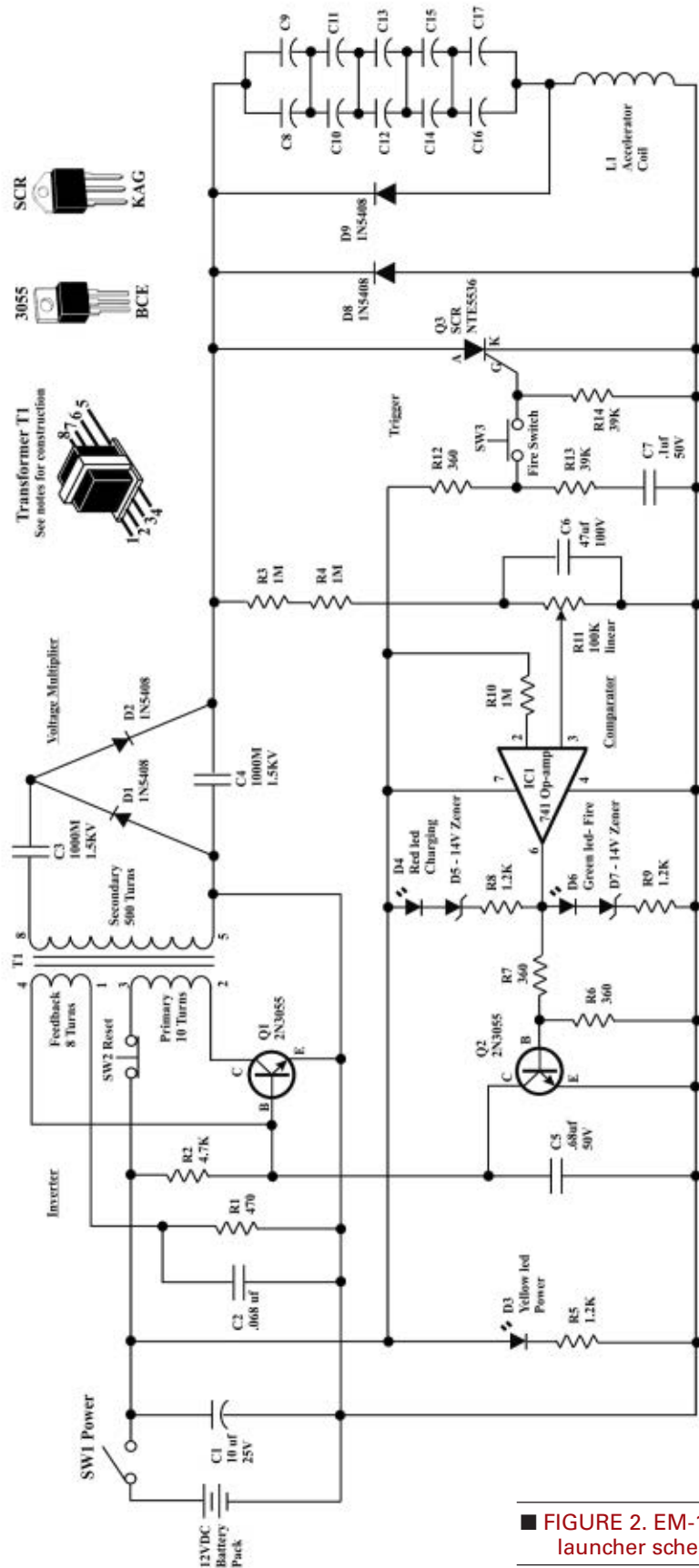
artificial nuclear disintegration in history. The two eventually won the 1951 Nobel Prize in physics for "Transmutation of atomic nuclei by artificially accelerated atomic particles." The voltage multiplier device was actually discovered earlier, in 1919, by a Swiss physicist named Heinrich Greinacher. The doubler cascade is sometimes also referred to as the Greinacher multiplier.

The capacitor storage bank is comprised of 10 1,500 μ F, 200V capacitors configured to achieve 600 μ F, 1,000V (C8–C17). These capacitors are available at most electronics supply companies. When the capacitor bank is charged to 800 VDC, the amount of energy that will be switched to the accelerator coil is 192 joules. With the capacitor storage bank charged to 1,000 VDC, the amount of energy is 300 joules. The capacitor bank should only be charged to 1,000 volts if you have installed an SCR that can handle it.

The 741 operational amplifier (IC1) is configured as a voltage comparator and is used to set the amount of voltage charge on the capacitor bank. The reference voltage for the comparator is taken directly from the 12 volt DC source through resistor R10. The voltage charge accumulating on the capacitor bank is dropped down to a value of approximately 1:20 through a voltage divider made up of resistors R3, R4, and 100K potentiometer R11, and is then connected to the comparator. The potentiometer is used to set the exact voltage level on the capacitor



■ **FIGURE 1. EM-15 electromagnetic coil launcher.**



bank when calibrating and using the rifle. Note that the capacitor bank is charged through the accelerator coil.

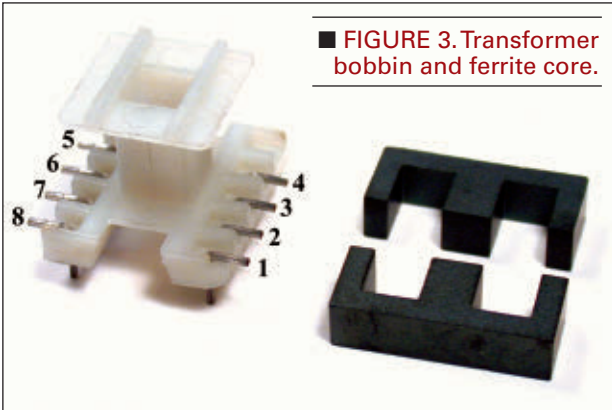
When the desired voltage has been reached, the output of the comparator goes high and turns on transistor Q2 and the fire indicator light emitting diode D6. When Q2 is switched on, the base of Q1 is pulled to ground which stops oscillation of the transformer, turning the charging action off. If the launcher is not fired immediately after fully charging, the voltage level on the capacitor bank will slowly start to decrease due to leakage and the comparator will turn the charging circuit back on to keep the capacitor bank voltage level topped off. You will notice the charge and fire LEDs gradually alternating on and off indicating that the comparator and charging circuit are maintaining the set voltage.

Once the capacitor bank has charged to the set level, a ferrous projectile is inserted into the breech loading device and positioned partially into the coil by the bolt. The bolt of the loading device has a small magnet in the end with enough force to hold the projectile in place if the launcher is tilted forward, but not enough to interfere with the operation of it. When fire switch S3 is closed, voltage is applied to the gate of the SCR, switching it on and dumping the charge across the capacitor bank into the accelerator coil L1. The accelerator coil creates an electromagnetic pulse that launches the projectile down the barrel. Diode D9 is required to prevent the voltage from reversing.

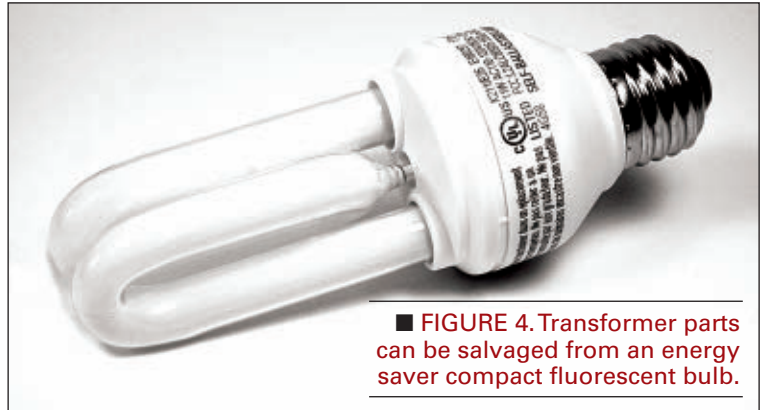
Transformer Construction

The heart of this project is a miniature high frequency transformer wound on a 20 mm x 17 mm x 15 mm bobbin with a ferrite core as shown in Figure 3. The primary winding consists of 10 turns of #26 AWG (American Wire Gauge) laminated magnet wire with an inductance of .008 μ H, the feedback winding is eight turns of #26 AWG with an inductance of .006 μ H, and the secondary winding is 500 turns of #34 AWG with an inductance of 20.6 μ H.

Electromagnetic Coil Launcher Project



■ **FIGURE 3.** Transformer bobbin and ferrite core.



■ **FIGURE 4.** Transformer parts can be salvaged from an energy saver compact fluorescent bulb.

All inductance measurements were taken with the iron cores in place.

If you can't locate a bobbin and core of similar dimensions at your local electronics store, then obtain a dead or unused energy saver compact fluorescent light bulb like the one shown in Figure 4. Crack open the lamp at the seam, being careful not to break the glass tube, and remove the circuit board. Locate the ferrite core transformer and unsolder it from the PCB (printed circuit board). Detach the core parts by unwrapping any tape that may be holding them together.

Use a knife or saw with a fine blade to cut the glue at the points where the core halves are in contact if the E-cores are glued together. There will probably be an air gap spacer on each side of the cores and in the middle so that the ferric material of each core does not contact. Don't worry about destroying the gaps because we will be adding our own later. Remove all of the wire

and tape from the bobbin.

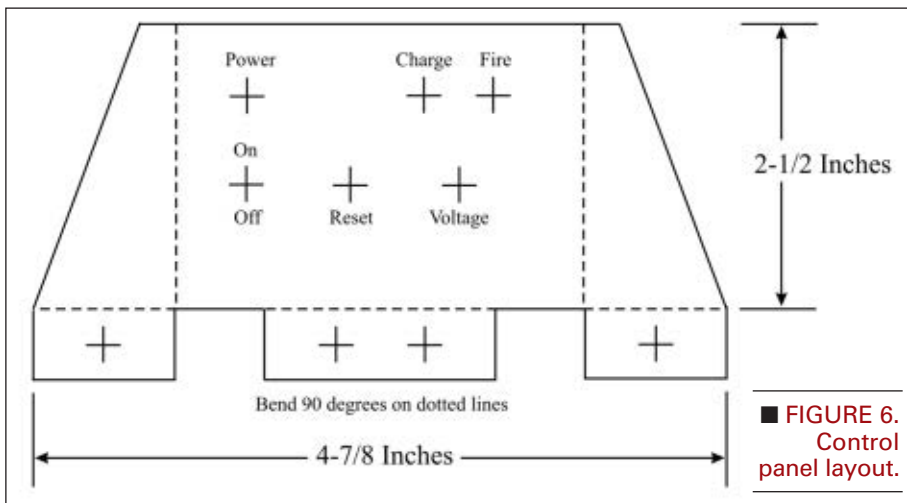
It's okay if your bobbin doesn't have terminal posts since connector wires can be used instead. You should now have a bobbin and E-cores similar to the ones shown in Figure 5-A.

Start by numbering the bobbin posts from 1 to 8 in the positions shown in Figure 3. Solder one end of a piece of #26 laminated magnet wire to post number 2 and then wind the primary coil of 10 turns clockwise around the top half of the bobbin as shown in Figure 5-B. Solder the other end of the primary winding wire to post number 3. Using another piece of #26 magnet wire, solder one end of the wire to post number 1 and then wind the feedback coil of eight turns on the bobbin clockwise below the primary winding as shown in Figure 5-C.

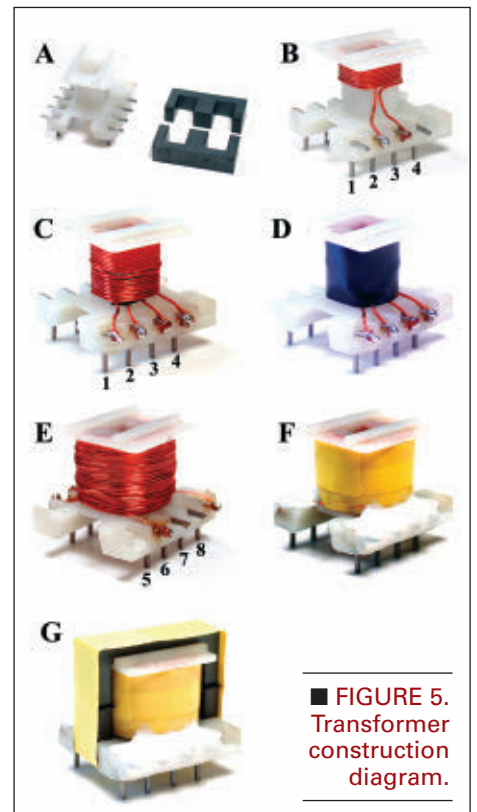
Solder the other end of the feedback winding to post number 4. Next, cover the primary and feedback windings with a layer of electrical tape as

depicted in Figure 5-D. On the other side of the bobbin, solder the end of a piece of #34 AWG magnet wire on post number 5 and then wind the secondary coil of 500 turns in even layers.

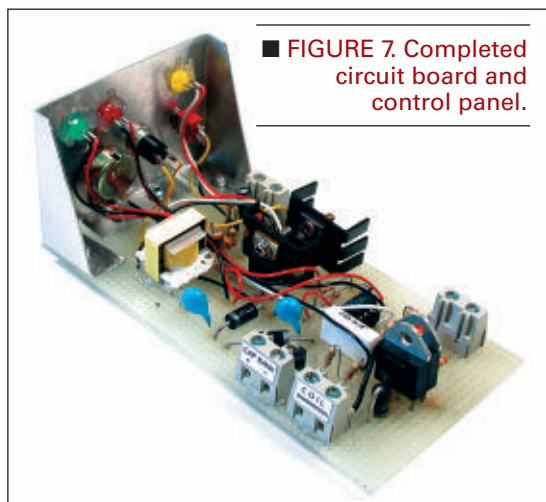
When hand winding the coil, you probably won't be able to get the layers perfect but it won't be a problem; just make them as neat as possible. Solder the other end of the secondary winding to post number 8 as shown in Figure 5-E. Wrap the secondary winding with a layer of transformer tape and then coat the solder connections with silicone rubber or a similar insu-



■ **FIGURE 6.** Control panel layout.



■ **FIGURE 5.** Transformer construction diagram.



■ **FIGURE 7.** Completed circuit board and control panel.

Building the Circuit and Control Panel

The circuit is constructed on a piece of 5-1/2 inch by 2-7/8 inch perfboard using the point-to-point wiring technique following the schematic. All of the parts necessary for the circuit are listed in the Parts List.

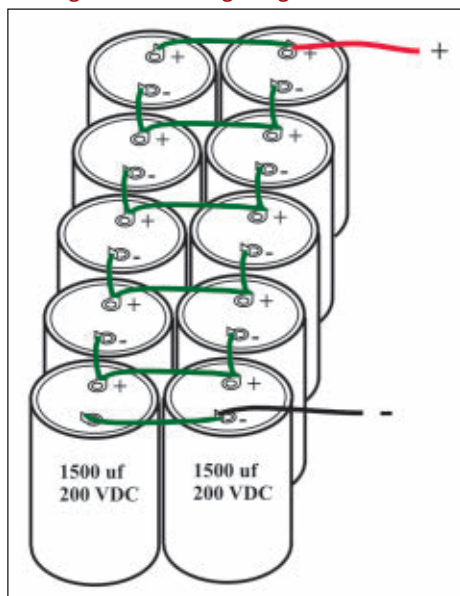
The control panel is constructed using 1/16-inch thick aluminum and can be mounted directly to the circuit board. A suggested metal cutting and drilling template is shown in Figure 6. Mount the

potentiometer, indicator LEDs, and switches to the control panel and then fasten it to the circuit board. Use two position terminal blocks on the board where the capacitor bank, battery pack, fire switch, and accelerator coil are connected. The completed circuit board with control panel attached is shown in Figure 7.

Capacitor Bank

Build the capacitor bank using 10 1,500 μF , 200 volt capacitors wired according to the diagram in Figure 8. This capacitor configuration gives a total capacitance of 600 μF at 1,000 VDC. Solder a 12 inch piece of high voltage wire to the positive side of the capacitor bank and a six inch piece of HV wire to the negative side of the

■ **FIGURE 8.** Capacitor energy storage bank wiring diagram.

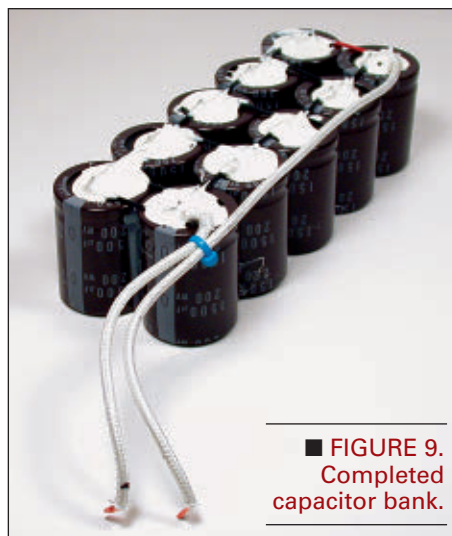


capacitor bank as shown in Figure 9. The length of these wires may be different, depending on what type of stock you decide to build. Coat all of the capacitor leads and solder connections with RTV silicon rubber or Plasti Dip for safety. The completed capacitor bank is shown in Figure 9.

Accelerator Coil, Barrel, and Breech Loading Mechanism

The barrel consists of a 14 inch length of styrene tubing with an inner diameter of 7/16 inch. You can use any sort of light plastic or nylon tubing material that can be obtained at most hobby shops. Wind 300 turns of #20 AWG magnet wire, in six layers of 50 turns each. Start winding the coil one inch from the end of the tube. Cover each layer of 50 turns with electrical tape to secure in place and then wind the next layer on top. Use two plastic or cardboard discs glued to each end of the barrel on both sides of the coil to add support.

Fabricate a breech loading device to move the projectile into a position where it is partially seated in the coil. You will need to experiment with the initial position of the projectile to achieve the highest velocities. The bolt of the loading mechanism that I put together contains a small magnet that holds the projectile in place when the launcher is tilted, but does not have enough magnetic strength to interfere with the pulse created by the accelerator coil. The completed accelerator coil, barrel, and breech loading mechanism are shown in Figure 10.



■ **FIGURE 9.** Completed capacitor bank.

Pistol Grip and Trigger Switch

The trigger switch used is a microswitch type but any momentary contact switch can be used. The pistol grip can be configured however you like, just as long as you can mount a fire switch. A general pistol grip construction template is shown in Figure 11 and can be fabricated out of plastic or aluminum.

Cut two identical pieces of plastic

Electromagnetic Coil Launcher Project

or aluminum and add support pieces of one inch square aluminum tube. Solder a length of two-strand wire to the common and normally open contacts on the microswitch. If you use a momentary contact switch, make sure that it is normally open.

Another alternative is to cut the pistol grip and trigger from one of the many inexpensive toys that are available on the market and rewire the switch. The completed grip with fire switch is shown in Figure 12.

Fabricating the Stock and Side Panels

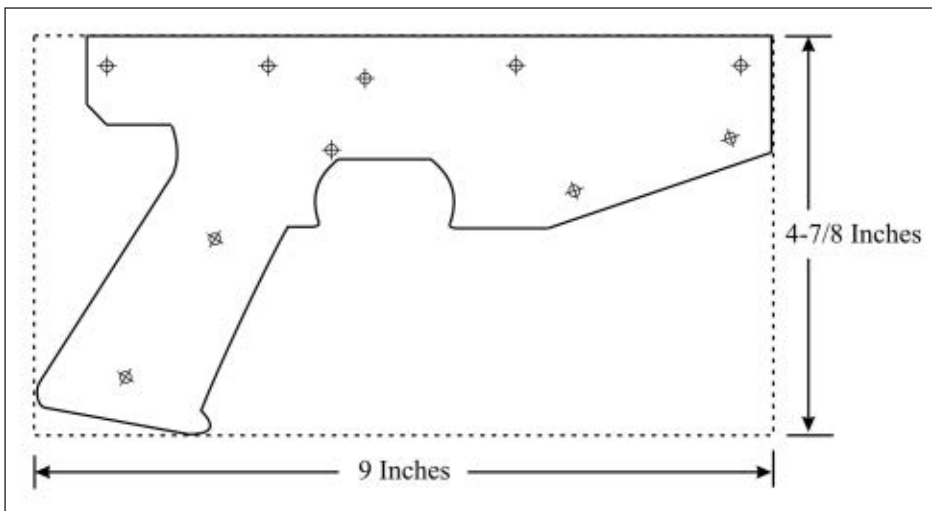
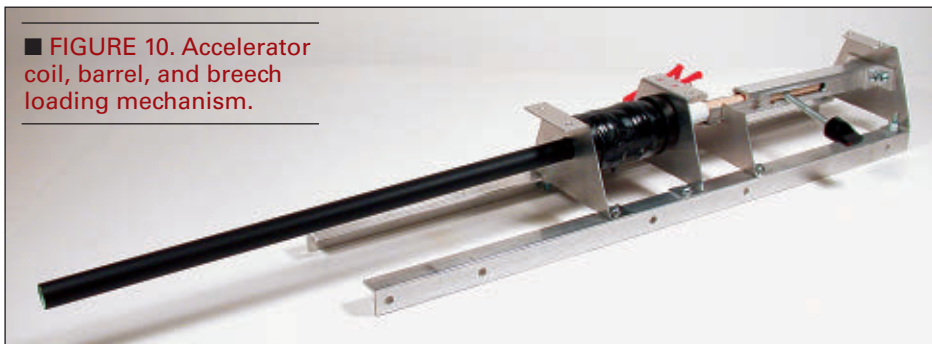
The stock for the EM-15 was fabricated with 1/2 inch aluminum angle and 1/16 inch thick flat stock but you can use whatever material you have access to. A metal bender was used to shape the pieces and all holes were made with a drill press. The side panels and covers are shown in Figure 13. The capacitor bank, side panels, and trigger assembly are shown in Figure 14. A closer view of the adjustable breech mounted to the rest of the launcher is shown in Figure 15.

Assembling and Calibrating the Gun

I suggest setting up all of the electronic components on your workbench to calibrate the launcher before assembling all of the parts into the stock. Connect the 12 volt battery pack, fire switch, accelerator coil, and capacitor bank to the circuit board. Be very careful not to touch the circuit board or any of the connections while testing the device. If you need to rewire or make an adjustment, then disconnect the battery pack and be sure to short out the capacitor bank.

Set your multimeter to measure DC and then clip the leads to the capacitor bank terminals. Place a fresh set of batteries into the battery holder and turn the voltage potentiometer R11 all the way counter-clockwise and then turn on the main power switch. The 'power' and 'charge' LEDs should turn on. You will see the voltage rise to approximately 350 volts DC at

■ FIGURE 10. Accelerator coil, barrel, and breech loading mechanism.



■ FIGURE 11. Pistol grip cutting guide.

which time the 'fire' LED turns on and the charging action will stop.

Mark 350V on the control panel at that position with a pencil or marker. Slowly turn the potentiometer clockwise until the voltage is 400 VDC and make another mark on the

panel there. Continue this procedure in increments of 50 volts until you reach 800 VDC, marking each position of the potentiometer on the panel face with a pencil or marker as you go. Be sure not to charge the capacitor

FOR YOUR INFO

The concept of electromagnetic launchers has actually been around for a while. The June 1932 *Modern Mechanics* magazine cover story featured an electric



cannon built by an English designer named Dr. Kapitza. The story reported that the firing of shells was accomplished by shortcircuiting powerful dynamos for periods of 1/100th of a second.

This approach sounds very similar to the modern compensated pulsed alternators (compulsators) being used to power the rail guns being developed at the University of Texas at Austin for the US Army electric gun program. For more information about the research going on at the University of Texas, visit their website at www.utexas.edu/research/cem/





■ FIGURE 12. Completed pistol grip with fire switch mounted.



■ FIGURE 13. Aluminum covers and side panels.

you find one that works well.

Firing and Velocity Measurements

Set up a proper backstop when you are ready to fire the launcher and *always* wear eye protection when operating the device. The velocities listed in Table 1 were measured with a commercial chronograph. The projectile used for the measurements was an eight gram crossbow tip like the ones shown in Figure 17. The EM-15 coil launcher stays well below the legal velocity limits in Canada and the US, but because of the projectile weight, it should still be considered dangerous. Regular firearm handling precautions should be taken.

Conclusion

The EM-15 coil launcher design can be used as a starting point for more advanced experimentation. Improvements can be made to the charging circuit, capacitor bank, accelerator coil, and barrel design to achieve higher velocities. Try designing a system with multiple coils, capacitor banks, and a switching device. A capacitor bank configured for higher capacitance and higher voltage can be used, but be sure to replace the SCR with one that can handle the increased voltage and amperage.

A design using a microcontroller to coordinate the switching, charging, voltage monitoring, and display would make a multiple coil design much easier to implement. The smooth bore

■ FIGURE 14. Capacitor bank, side panels, and trigger assembly.

bank over 800 volts unless you have installed an SCR that can handle it. The control panel and circuit board can be seen in Figure 16.

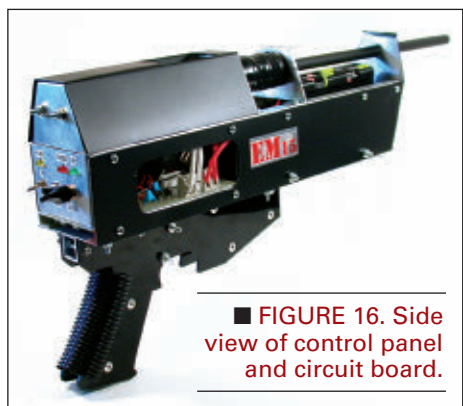
Suitable Projectiles

A 1/2 inch projectile can be cut from a piece of .30 diameter cold rolled steel and then filed on one end for a more aerodynamic shape. I found that iron crossbow/archery tips (available at Wal-Mart) make ideal projectiles for this type of coil launcher. Three of the different projectiles that I have used with success are shown in Figure 17.

If you decide to fabricate your own projectiles, then experiment with different sizes and weights until



■ FIGURE 15. The adjustable breech is ideal for experimentation with different types and initial positions of projectiles.



■ FIGURE 16. Side view of control panel and circuit board.



■ FIGURE 17. EM-15 coil launcher projectiles.

COIL LAUNCHER RESOURCES

EM-15 coil launcher website
www.thinkbotics.com/military.htm

World's coil launcher arsenal
www.coilgun.ru

The gauss pistol
www.gausspistol.com/index.html

Another coil launcher site
www.anothercoilgunsite.com

Coil launcher systems
www.coilgun.eclipse.co.uk/

barrel causes problems with accuracy because the projectile does not spin to stabilize it while in motion. Try to come up with some sort of rifled barrel or perhaps adding stabilizing fins to the projectile.

Remember that safety always come first when building and experimenting with high voltage and ballistics. For more information about the project, updates, and movies of the launcher in action please visit the EM-15 Coil launcher webpage at www.thinkbotics.com/military.htm **NV**

COIL LAUNCHER FROM THE PAST



An interesting story was printed in the November 1936 issue of *Popular Science* about an electric machine gun. The gun was built by Virgil Rigsby of San Augustine, TX and was also featured earlier in a 1934 issue of *Modern Mechanix*. It was claimed that the gun could fire 150 rounds per minute using a series of electromagnets positioned along the barrel.

Voltage	Projectile Weight	Velocity (ft/sec)	Velocity (meters/sec)
400	8 grams	57	17.37
500	8 grams	64	19.51
600	8 grams	70	21.34
700	8 grams	81	24.69
800	8 grams	91	27.74
900	8 grams	101	30.78
1,000	8 grams	129	39.32

■ TABLE 1. EM-15 velocity measurements.

EM-15 ELECTRONICS PARTS LIST

ITEM	DESCRIPTION	QTY
RESISTORS (All resistors 1/4 watt 5% tolerance)		
□ R1	470Ω	1
□ R2	4.7K	1
□ R3, R4, R10	1M	3
□ R5, R8, R9	1.2K	3
□ R6, R7, R12	360Ω	3
□ R11	100K linear potentiometer	1
□ R13, R14	39K	2
CAPACITORS		
□ C1	10 μF 25V electrolytic	1
□ C2	.068 μF	1
□ C3, C4	1,000 μF 1.5 KV	2
□ C5	.68 μF 50V	1
□ C6	47 μF 100V	1
□ C7	.1 μF 50V	1
□ C8-C17	1,500 μF electrolytic @ 200V	10
SEMICONDUCTORS		
□ Q1, Q2	2N3055 NPN transistor with heatsink	2
□ Q3	NTE 5536 SCR 800V	1
□ IC1	741 operational amplifier	1
□ D1, D2, D8, D9	IN5408	2
□ D3	Yellow LED	1
□ D4	Red LED	1
□ D6	Green LED	1
□ D5, D7	14V zener	2
MISCELLANEOUS		
□ T1	Transformer — see text for details	1
□ SW1	Single pole single throw	1
□ SW2	Normally closed push button	2
□ SW3	Microswitch or push button normally open	1
□ L1	Accelerator coil – 300 turns of #20 AWG magnet wire	1
□ HV wire	High voltage wire	18 inches
□ Barrel	7/16 inch diameter, 14 inches long	1
□ Battery pack	12 volts (1.5V AA x 8)	1
□ Terminal block	Two position	4

How To Choose An Operational Amplifier

by Gerard Fonte

There are probably thousands of operational amplifiers (op-amps) available. But which one is the best for your particular application? A datasheet has lots of numbers and graphs, and then there are the many strange acronyms. This article will show you how to wade through the jargon and select the op-amp that best fits your needs.

There are some basic items that need mentioning before we start. The first is that we will only examine basic op-amps. We will not look directly at special types, like high frequency (10s to 100s of MHz), current-difference, or trans-conductance. However, once

the basic op-amp is understood, it is a small step to the special types.

Another point is that you have to know what your circuit needs. This seems obvious but it is sometimes overlooked. Trying to use a five-volt op-amp in a 25 volt circuit generally guarantees poor performance. More subtly, using an op-amp that doesn't have the proper frequency range or is too noisy is not a rare occurrence. You must fully understand your requirements to make a proper selection.

An ideal op-amp has no distortion, uses no meaningful power, has infinite amplification, generates no noise, has infinite input resistance (to present no load to the signal being amplified), has infinite frequency response, accepts signals of any voltage and, of course, is free. While modern devices can come close to some of these ideals — like input resistance and low power — no amplifier can achieve them all.

Figure 1 illustrates some of the

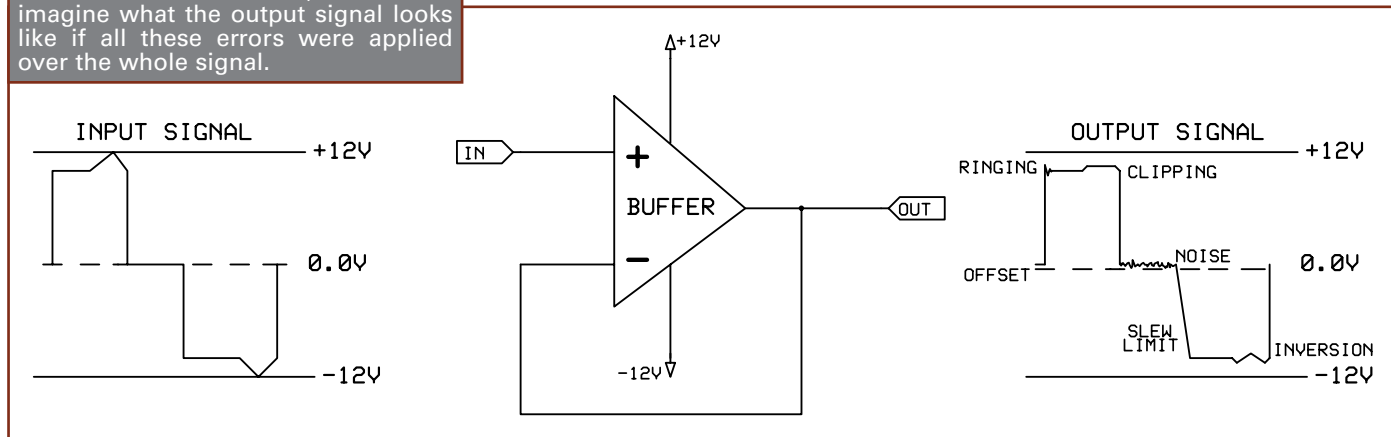
typical imperfections found in op-amps. (Note that the problems are shown in isolation for clarity. In reality, most of these effects are continuous and compounded.) This means that you must choose between different amplifiers with different strengths and weaknesses. This is the typical situation of engineering trade-off.

Basic Op-Amp Specifications

All op-amp data sheets have a section labeled "Absolute Maximum Ratings." I call these the "Fry Points" because operating the device at these (or higher) levels will fry it. You can never exceed these ratings and expect anything good to happen. You should always stay well below these values. The datasheet will usually specify, in some manner, standard maximum operating levels.

Many datasheets will have "Typical" numbers. A good engineer

FIGURE 1. A real op-amp is not perfect. The output signal displays a number of typical failings. Note that the problems are only shown once for simplicity. Ringing occurs at every fast transition while noise is continuous, etc. You can imagine what the output signal looks like if all these errors were applied over the whole signal.





pretty much ignores them. The worst-case values should always be used to guarantee proper performance. If you are simply making one item for your own use, you might take a chance and/or hand-select an op-amp for your project. But this approach is not acceptable in a professional setting (except under rare and very special conditions).

The table of specifications in most datasheets is presented in alphabetical order. This may be useful in finding a specific value, but it does not provide any coherence to the information. Here, the specifications will be organized into groups that are related in some way. Four basic groups will be used: Power, Input, Output, and Frequency. Note that these groups are not independent of each other. Defining your design with these four factors is pretty straightforward and intuitive.

Power

First and foremost it must be noted that there is no “Ground” pin on an op-amp. Thus, any and all op-amps can operate from a single supply. So why are some op-amps specified as requiring positive and negative power supplies? This is because the input is assumed to be at ground and that AC input signals will move above and below ground. It is clear that if the input voltage exceeds either power supply (either more positive or more negative), bad things will happen. This is one of those notes mentioned in the Absolute Maximum Ratings entry. The input voltage **MUST** be within the range of the power supply. (More on this in the Input section.)

The operating voltage (identified as V^+ and/or V^-) is often specified in a separate table and/or in the text of the datasheet. Way back when, it used to be that ± 15 volts (or even higher) was the standard (bipolar or dual power supplies). Nowadays, many op-amps are specified as needing between $+3$ to $+15$ volts (unipolar or single supply). This still means that the inputs to the op-amp must be within the power sup-

ply (although those noted as “single supply” op-amps allow the input to go to the negative rail ... usually ground).

Thus, negative voltages are not allowed at the inputs with this single supply specification. Also, the common use of two nine-volt batteries (one for V^+ and one for V^-) will result in 18 volts between the power terminals. This exceeds the Fry Point for these devices. So be careful to read the power specifications properly. Obviously, you know what voltages are available so this specification is easy.

The power supply rejection ratio (PSRR) identifies how sensitive the op-amp is to variations in the power supply. You don’t want power supply noise (from AC supplies) or drift (from batteries) to affect the output. This specification is listed as a decibel (dB) value where every increase by 20 dB is a 10-fold increase in the ratio. So, a 60 dB value here means that a one volt change in the power supply will cause a 0.001 volt (or one millivolt) change in the output.

This value depends on the actual power supply voltage, as well as the frequency of the noise. Higher operating voltages and lower noise frequencies generally result in better PSRR figures. Often, datasheets will provide graphs showing these variations.

Determining what you need for this parameter is not too difficult. If you are using an op-amp with digital logic (which typically causes a lot of power supply noise), you will want an op-amp with a good PSRR rating. If your op-amp is a fully analog design with a good, regulated analog power supply, then this parameter probably isn’t too important.

The current needed to power the amplifier is defined as the supply current (I_s). This is the quiescent current. This does not include external components or any output current. If there are multiple amplifiers in a single package, this usually refers to a single amplifier. However, the datasheet will specify this. Clearly, battery-operated circuits will work longer with an amplifier that uses less power.

Sometimes this is listed in milliwatts (or microwatts) as power consumption (Pd). So, you will have to convert it to mA (or μA) using the power supply voltages listed in the table.

Input

There are many input parameters and this group often contains the most important items that define the op-amp’s performance for a particular application.

The first basic specification is the input resistance (R_{in}) (sometimes it is referred to as input impedance). This indicates how much load the op-amp places on the signal. This value should be as high as possible (however, for very high speeds this will be relatively low because parasitic capacitance can affect the frequency response significantly). Obviously, you don’t want your op-amp to affect the signal you are amplifying. Values in the 100s of megohms are typical. Some of the newer op-amps have input resistances so high that they are not directly measurable ... greater than 10 teraohms! (A teraohm, or $T\Omega$, is 1,000,000 megohms.) (Note that the input capacitance is not usually given, but is very low; on the order of a pF or so ... mostly due to the leads.)

Occasionally, older specsheets provide only an input bias current (I_b) rather than an actual input resistance. This says how much current is needed to drive the inputs. It can be roughly converted to an input resistance by using Ohm’s law with the supply voltage. For example: If the I_b is 170 nA (nanoamps) and the supply voltage is five volts, then Ohm’s law is $5V = 170 \text{ nA} \times R_{in}$. Solving this gives about 29 megohms as the input resistance.

The input offset voltage (V_{os}) and input offset current (I_{os}) sound similar to the input bias current (above) but are very different animals. These refer to the inaccuracy of the amplifier and should be as close to zero as possible. If both inputs to the op-amp are zero, then the output should also be zero. But since the amplifier isn’t perfect,



there will be some residual voltage at the output. So why not call this the output voltage error? This is because the gain of the circuit will affect the output. A circuit with a gain of 100 will increase this error by a factor of 100. That is why this is referred to the input rather than to the output. It appears to the circuit like a DC error at the input. In fact, the definition of offset error is the voltage (or current) applied to the input to force the output exactly to zero.

Offset errors are generally not too important to AC circuits because the effect is seen as a fixed DC error. Since AC circuits are generally capacitively-coupled, the DC problem goes away. However, large gains (1,000 or so) can turn a 5 mV V_{os} into a five volt DC error at the output. This could possibly cause the amplifier to try to generate an output voltage greater than the supply voltage and lead to clipping.

Offset errors are critical in DC applications because it is impossible to separate out the real DC signal from the DC error. If you are trying to measure a 5 μ V signal from a thermocouple with an amplifier with a 5 mV V_{os} , you are going to have problems.

Associated with V_{os} and I_{os} is the change that occurs with these values are over temperature (TCV_{os} or TCI_{os}). Again, this is not too important for AC applications but may certainly be important for sensitive DC circuits. A 3 μ V DC change per degree may make your circuit more sensitive to temperature than your thermocouple!

There are limits to the input voltage you can apply to the amplifier and expect it to work properly (which is different from the Fry Points). This is called the common mode voltage range (CMVR). Many (probably most) new amplifiers have “rail-to-rail” inputs which permit you to use any voltage up to and including the V^+ and V^- voltages. Conversely, many amplifiers (especially the older ones) limit the input voltage to a fixed voltage less than the V^+ and V^- supplies (typically about 1.5 volts).

Keeping the input to a volt or so below the V^+ supply isn't hard. But if you are using a single supply, you may have to keep your signal a volt or two above ground, as well. This may not be trivial. Additionally, this can limit your input voltage range when using a low voltage. For example, if you use a single +5 volt supply and the amplifier requires ± 1.5 volts of headroom, you must keep your input signal between 1.5 and 3.5 volts. For single supply operation, it makes sense to choose an amplifier that “includes ground” in the CMVR. (Note some older amplifiers will invert the signal if it goes more negative than the negative CMVR!)

Another specification that sounds related but isn't is the common mode rejection ratio (CMRR). This refers to an error in the balancing of the inputs. Theoretically, if the inverting and non-inverting inputs of an op-amp are connected together, the output should be zero regardless of the voltage applied to the inputs. Again, perfection cannot be achieved.

CMRR is specified in dBs and is often 60 to 80 dB or more. So, a CMRR of 60 dB means that there can be an input error of 0.1% in the balance between the inputs. A five volt signal applied to both inputs, or V_{cm} (with 60 dB of CMRR), would appear to be a five volt signal applied to one input and a 5.005 volt signal applied to the other. The actual output error depends on the gain of the circuit.

The CMRR error is especially important when measuring a small signal embedded in a large one. For example, monitoring the power supply current requires measuring the tiny voltage drop across a small resistor in the presence of the full power supply voltage. This may entail measuring fractions of a millivolt in the presence of 10 or more volts. However, for most single-ended applications (where one input is connected to ground) the CMRR is not all that critical.

The input characteristics of the op-amp are important because they must match the signal you want to

amplify. These are a bit more complicated than the power requirements, but once you decode the jargon and the acronyms, the parameters make sense.

Output

The large signal voltage gain (A_v or A_{vo}), usually listed as a dB value, indicates the maximum amplification possible without any feedback. This amplifier configuration is rarely used as such, but this parameter specifies the limit of the device. Obviously, if the A_{vo} is 100 dB, you can't expect to make a 120 dB gain stage with that amplifier. In real life, it's very rare to have even 60 dB of gain (amplification factor of 1,000). Sometimes the A_{vo} is stated as a ratio, typically something like 60 V/mV. This indicates that there is a gain of 60,000 or about 96 dB. Modern amplifiers can have an A_{vo} of 130 dB or more. That's an amplification factor of over two million!

The maximum power output the amplifier can provide is generally listed as the output short circuit current (I_{sc}). Often this is in the 20 to 40 mA range. However, there are some early amplifiers that can provide only a few mA. Worse, some op-amps can't tolerate an output short circuit without burning up. Such a situation should be listed in the datasheet, but it may be hard to find. Typically, it will be identified in the small print notes at the bottom with something like: “Continued short-circuit operation can cause excessive die temperatures above the maximum rated value.”

The maximum output voltage (V_o) can never reach the limits of the supply voltage(s). The output will always be lower. There are some newer devices that claim rail-to-rail outputs. And they do approach the rails very closely — sometimes to within a few millivolts. But there is always a limit. (By the way, the distortion increases greatly if these rail-to-rail amplifiers are driven to their output extremes.) It is more usual for the V_o to be about 1.5 volts less than the sup-



ply. So, for a five-volt, single-supply operation, the output cannot be driven below 1.5 volts or above 3.5 volts.

Frequency

Up to now, we've been discussing the DC parameters. Now we'll touch on the AC parameters. These are the factors that specify how well the amplifier responds to actual signals. There are three general areas of AC specifications: speed, noise, and distortion.

The speed of an amplifier can be measured in a number of ways, but they are all related. The most typical measures are: slew rate (SR), unity gain bandwidth (BW), and gain bandwidth product (GBW). Fundamentally, the speed of an amplifier depends upon how fast the output can change. The SR measures the speed at which this happens. It is usually defined in volts/microseconds. But there is a fine point here. If the output is small, it doesn't move as much as a large signal, so a small output signal can respond to a higher frequency. This requires a bit of discussion.

When a signal is amplified, it has the effect of increasing the slew rate of the original signal equal to the amount of gain. For example, if a one volt signal is amplified by a factor of 10, then the output must move from zero to 10 volts in the same time the input moves from zero to one volt. Thus, there is an increase in the slew rate by a factor of 10, too. From this, we see that the maximum output frequency of a typical voltage-type op-amp is directly dependent upon the gain of the circuit.

There will be a certain high frequency where the amplifier can't keep up with the signal and the input and output are the same voltage, regardless of the external circuit design. This is the point where the gain equals one — or unity gain. Since the op-amp has DC as the lowest frequency, the highest operating frequency is also the bandwidth of the amplifier. Therefore, we see how the BW value is obtained.

The direct relationship between SR and gain means that there is a simple calculation that identifies the maximum frequency obtainable at any given gain. It can be seen that by reducing the frequency by two (in the example above), the gain of the circuit can be increased by two. Thus, the product of gain and frequency is always the same. This is the GBW.

If you want to amplify a signal by a factor of 100, then your maximum useable frequency is 1/100 of the BW. The BW and GBW are the same for the special case where the gain is one. (Note that the maximum amplification factor is limited by the open-loop gain (A_v) of the amplifier.)

Since this parameter is often overlooked, let's examine a simple example. Suppose you are designing an optical fiber interface. The switching speed is 100 kHz and you have to amplify the optical signal by 1,000 to make it big enough to trigger your digital circuit. How fast must the amplifier be?

To determine this, simply multiply the gain and frequency together. The result is 100 MHz. You need an amplifier with a 100 MHz GBW. Since this is much faster than any general-purpose amplifier, you will have to either employ one expensive and difficult to use high-speed op-amp or use multiple stages of amplification. In this instance, two gain stages of 32 will provide a gain of 1,024 and require two amplifiers — each with a GBW of 3.2 MHz. Many common and inexpensive op-amps have this GBW.

There are a number of types of noise. And the discussion of op-amp noise can quickly get very technical and detailed. However, there are two important types of noise that we will briefly look at. They are voltage noise (E_n) and current noise (I_n). Other than the fact that one is a current and the other is a voltage, these noise sources are treated in the same manner. Both are considered with respect to the input. This means that they will increase with increasing amplification or gain. An amplifier with a gain of

100 will have 100 times the noise that is specified.

The other point about this specification is that the noise is related to the bandwidth of the system. As such, they are defined with the "square-root-Hz" in the denominator (also called root Hertz). A wide-band circuit will have more noise than a narrow band circuit.

There are a number of other types of noise, as well as many other noise considerations. The purpose of this discussion is only to provide a basic understanding of how these noise values are defined. Obviously, a lower-noise amplifier is preferred to a higher-noise amplifier. But it is beyond the scope here to discuss how to determine if current or voltage noise is most important in your circuit, how to determine the best bandwidth for your circuit, etc.

The last set of specifications refer to the distortion generated by the amplifier. It is becoming more common for the distortion of the amplifier to be directly specified in the datasheet, which is a very straightforward method. (This generally wasn't the case.) Total harmonic distortion (THD) is listed as a percent value. Normally, this is a very low value on the order of 0.01% or better.

Another method of specifying how faithfully the amplifier responds to a signal is with the "transient response" parameter. This specifies how the amplifier reacts to an abrupt change. Virtually all op-amps will exhibit overshoot in this situation. This overshoot is listed as a percentage of the output signal. Several percent or higher is typical.

The AC characteristics are much more subtle and complex than the DC characteristics. However, you should certainly know the frequency requirements you need. Noise factors are important in high-gain, wide-band circuits. Most op-amps have distortion levels that are quite acceptable. However, if you are using them to condition a signal to a 16-bit Analog-to-Digital converter (that's one part in

65,536), you will need a THD of 0.001% or better.

Graphs

Lastly, there are many graphs displayed in the datasheet. This is because many of the parameters vary according to frequency, voltage,

temperature, etc. These graphs indicate how the op-amp performance is expected to change. Note that these are usually typical values, so don't expect your particular unit to exactly match these measurements. The graphs are presented to indicate response trends, not response specifications. For example, it may be impor-

tant to know if the input bias current increases or decreases with temperature and roughly by how much.

Cost versus Performance

You can buy the LM741 op-amp for about a quarter. And quite honestly, it may be adequate for the task. But it has an input resistance of only 300,000 ohms, requires two power supplies, drifts badly with temperature, and the noise is not even specified. You get what you pay for.

I opened my *National Semiconductor Data Book* more or less randomly and found the LPC660. It has about the same speed as the LM741 and costs about \$3. But for this price, you get four amplifiers in one package, so the cost per amplifier is only about \$0.75. It is a single supply amplifier (from 5V to 15V) with rail-to-rail outputs, >1 teraohm input resistance, drifts 1/10 of the LM741, and uses about 1 mW of current per amplifier (about 1/100 of the LM741). (The savings in battery cost far outweigh the increase in the op-amp price.)

The point of this brief comparison is to show that analog electronics have evolved substantially. It is truly amazing what a dollar or two can buy. But if you don't know what to look for, you can't find the best part for your money. If you want your project or product to provide peak performance and in the most cost-effective manner, take the time to see what's available. Spending a little effort at the start can provide you with incredible analog performance.

Conclusion

Choosing an op-amp requires matching your needs to the op-amp datasheet. Blindly assuming that any op-amp will work in any circuit is only going to result in frustration and disappointment. Conversely, using the proper op-amp can allow you to do things you never thought were possible. **NV**

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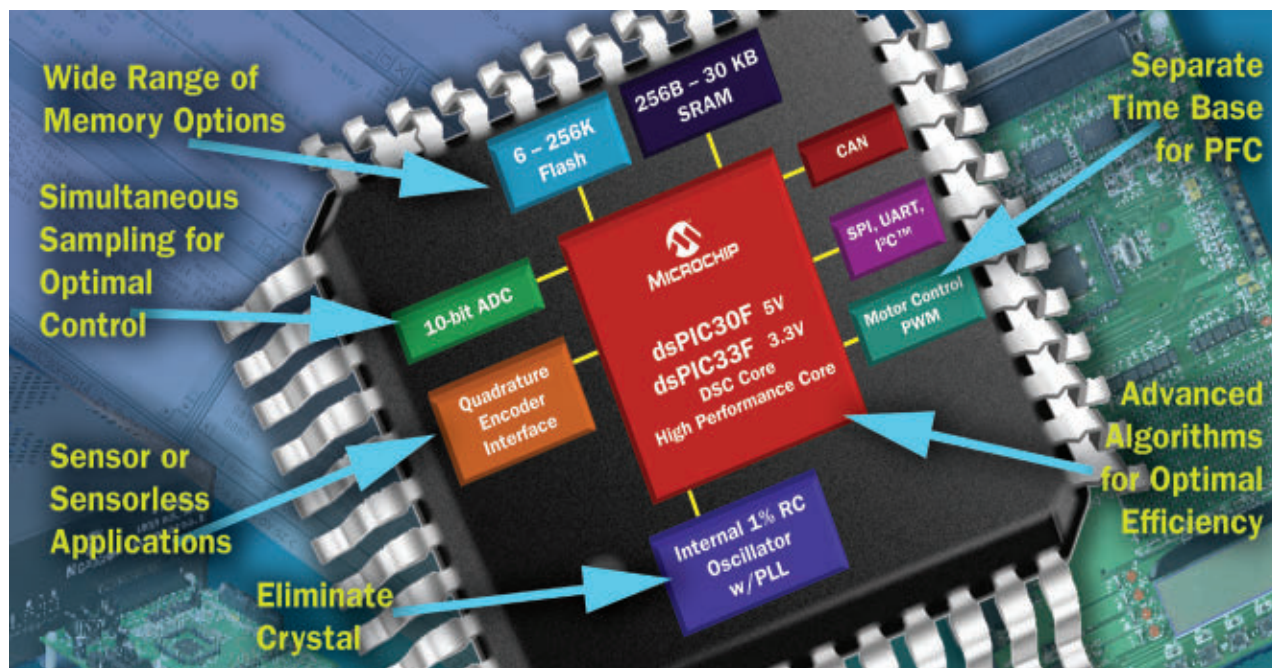
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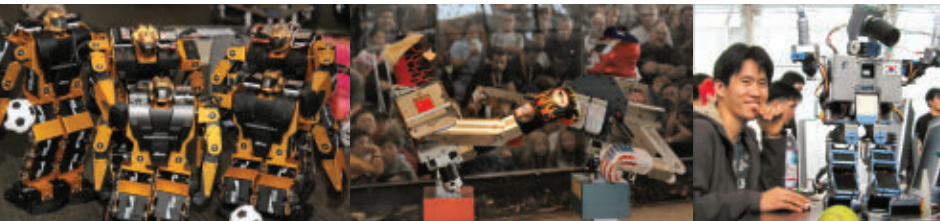
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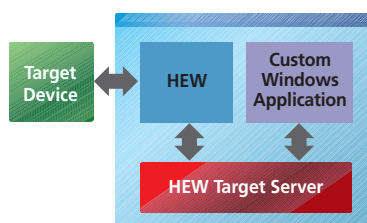
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TIME *after* Time ...

by Norm Looper
Chief Engineer,
Analog Scientific, Inc.

*A Nuts & Volts Designer's Guide to
reliable oscillators and timers.*

**“Nothing works
just for you ...
you gotta make
the damn
thing work.”**

– Thomas Alva Edison

Common Problems in the Design of Digital Oscillators and Their Remedy

Electronic designers are familiar with the apparent perversity of Nature in the tendency of amplifiers to oscillate and oscillators to amplify. But even the beginning designer knows that questions of oscillation and stability involve feedback — that ubiquitous structure in natural systems and many

man-made ones — whereby a fraction of the system's output energy is fed back to the input to produce useful effects. It is the specific character of this feedback that determines what effects will be produced at the output.

So-called relaxation oscillators function by accumulating energy in some kind of reservoir (electrical,

chemical, mechanical) and then “relaxing,” or removing it. This process is then repeated, and the overall time required to fill and empty the reservoir is called the period of oscillation; the reciprocal of the period is termed the frequency of oscillation.

A Common Relaxation Oscillator

A bad example can often be very instructive. Figure 1 depicts a common digital oscillator implemented with logic gates (Ref. 1). While I am reluctant to call this oscillator “bad,” I have never been entirely comfortable with it. This oscillator, or one like it, is occasionally seen in published literature. In this form, the [R1,C1] tank circuit is commutated across the output inverter between V1 and VO. I don't like the functioning in this circuit above about 150 kHz and the fidelity of the waveforms erodes when C1 is

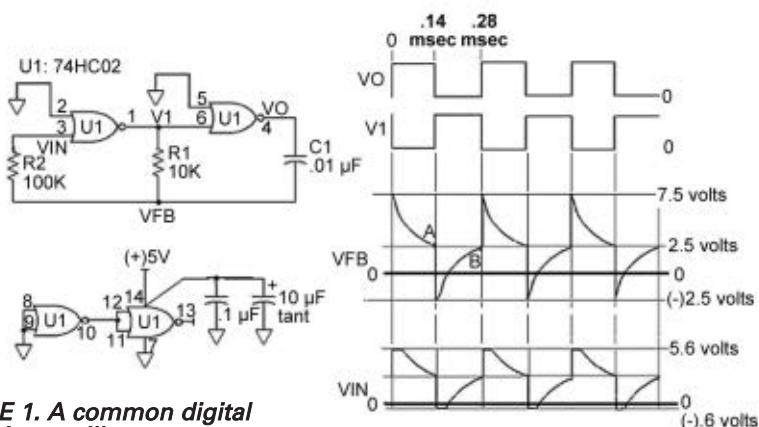


FIGURE 1. A common digital relaxation oscillator.

less than 1,000 pF. What are the other deficiencies here?

1) The logic gate has no well-defined input thresholds. Near an input voltage of approximately $V_{CC}/2$, this alleged digital device behaves as a high-gain linear amplifier. Normally, this input region is transitioned very rapidly in pure interconnected logic and is not a problem, but when passive components are added as loads, this may not be the case.

2) Since passing through the input “no man’s land” near $V_{CC}/2$ must be done rapidly, each CMOS logic family has a minimum input slew rate requirement. For example, the 74HC family specifies a fast rise time of at least 11 volts/microsecond. This is not a problem when gates of the same family are interconnected directly, but addition of an RC tank circuit imposes slower ramps near $V_{CC}/2$ as shown in the Figure’s timing diagram at node VFB, at times A and B. Here the form of the circuit forces a slow decay near the input transition points, with a slew rate of only .022 volts/microsecond for the values shown. Although the gate tolerates this, we are asking for trouble.

You will often find a very high frequency burst oscillation at VFB, points A and B, for a few microseconds. Further, any noise on the output, typically from the power and ground rails, is fed back to node VFB through C1 — producing frequency jitter, known as phase noise. Of course, one can employ a slower logic family, such as first generation 4000 CMOS digital logic, which has a slower minimum input slew rate, but this approach attempts to compensate for a defect in the form of the circuit with a lack of performance of the logic gate.

3) An even number of gates have been used to produce 360 degrees of overall phase shift and induce oscillation. This requires that the RC tank circuit should introduce no additional phase shift in the feedback loop — accordingly, a differentiating circuit

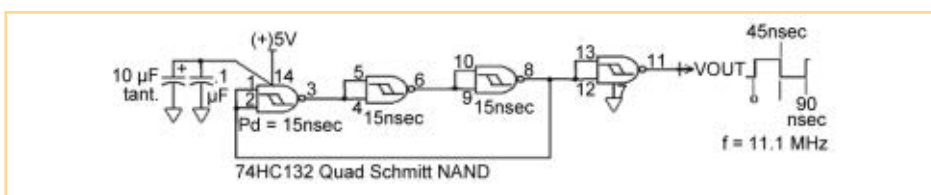


FIGURE 2. A classic ring oscillator.

Note that the observed propagation delays are actually less than specified.

The Ring Oscillator With a Tank Circuit

A superior oscillator to Figure 1 can be achieved by adding an RC tank circuit to the ring oscillator of Figure 2, as shown in Figure 3. Note that the resistor and capacitor have been swapped in position, but are still commutated between the outputs of the last two inverters. Now the output has a DC path to the input. As in Figure 1, the differentiating circuit allows a non-Schmitt inverter to again be used. This is a better form than Figure 1, but rather than invest time on designing to it, let’s move on to an even better oscillator.

A Better Oscillator

Refer to Figure 4. Of course, we can always realize a utility oscillator using the CMOS 555 timer, but this can be expensive. Your design may have leftover NOT and NAND Schmitt gates that can be usefully employed. Note that RC relaxation oscillators that employ digital logic gates are not precision devices and are without tight tolerances on frequency. They are generally suitable only for utility clocking.

Figure 4 details a simple oscillator that uses only one NAND gate within a 74HC132 quad Schmitt NAND integrated circuit. An inverter within a

Understanding Propagation Delay in RC Relaxation Oscillator Design

A comprehensive representation for understanding high speed digital gates includes propagation delay. Consider Figure 2, where we see three inverters in series. I have used Schmitt inverters here to give a crisp threshold action and prevent spurious oscillations.

When V_{CC} is applied to the circuit, noise and drift at the inputs will initiate stable oscillation directly after a short transient interval. Since each gate has a response time — or propagation delay — of about 15 nanoseconds, we will see at VOUT a 45 nanosecond pulse (3×15 nanoseconds) that will travel continuously around the loop, with a spacing of 45 nanoseconds, producing an output frequency near 11 MHz — without any RC tank circuit whatsoever! We have a classic, free running “ring” oscillator.

The propagation delay sets an upper limit to the frequency of oscillation, since addition of RC elements to the feedback will lower this frequency to practical values well below this. Build the actual circuit in Figure 2 and try it!

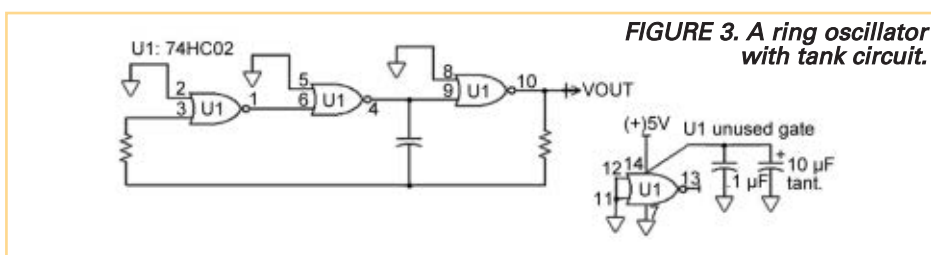


FIGURE 3. A ring oscillator with tank circuit.

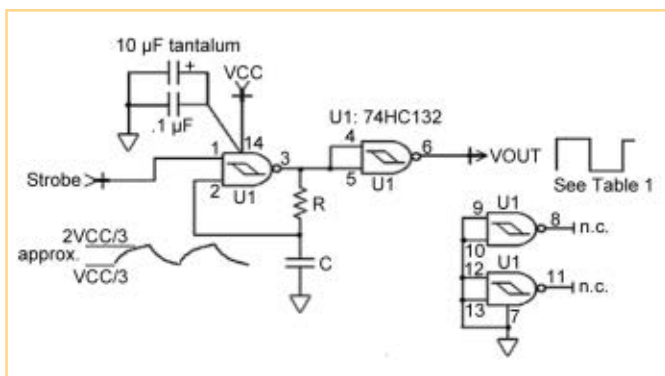


FIGURE 4. A better oscillator.

without any tank circuit (i.e., $R = 0$ and $C = \text{parasitic pF}$) – will free run at roughly 40 MHz, and we should prudently limit our design to 5 MHz or less to avoid anomalous operation and temperature drift.

Note the following constraints for the tank circuit. The tolerance on V_{CC} should be strictly observed, while the limits on R and C are approximate.

$$2 \text{ volts} \leq V_{CC} \leq 6 \text{ volts.}$$

$2K \text{ ohm} \leq R \leq 2M \text{ ohms}$. Use 1% tolerance metal film units, leaded or surface mount.

$100 \text{ pF} \leq C \leq 1 \text{ microfarad}$. Use 2% or 5% tolerance, NPO or X7R dielectrics for surface mount capacitors. Polyester or polycarbonate film are good choices for leaded units. See text for $C > 1 \text{ microfarad}$.

A Schmitt trigger involves positive feedback within the gate itself and produces a middle input dead band where no output transitions are allowed. The upper and lower thresholds of this device's input dead band reside at roughly $V_{CC}/3$ and $2/3 V_{CC}$. These thresholds can vary greatly from unit to unit, and between the four Schmitt NAND gates within a given unit.

The dead band and duty cycle also varies with V_{CC} , but not strongly so, being partially ratiometric to it. The charging of the RC tank is exponential, but a simple table incorporating all of these factors can be computed to simplify the design (see Table 1) which gives the value of a lumped numerator in an equation to determine the required RC time constant of the tank circuit in Figure 4. Simply dividing the desired frequency of oscillation into this numerator immedi-

TABLE 1. Required RC time constant = Numerator/frequency.

ately gives you the required RC time constant. This done, values of R and C can then be selected.

Example: What RC time constant is required to produce a nominal frequency of oscillation of 100 kHz when $V_{CC} = 5.0$ volts?

Solution: $R \times C = \text{numerator} / 1 \times 10^5$
 $= 1.194 / 1 \times 10^5 = 1.194 \times 10^{-5}$
 seconds = 11.94 microseconds.

Now we want to select an appropriate resistor and capacitor to produce this RC time constant. To sharpen your design sense in these matters, note that resistors over two megohms will start showing sensitivity to humidity, and capacitors over one microfarad will typically require tantalum or aluminum electrolytic implementations, where leakage may start to be comparable to the charging currents when the selected resistor increases in value.

Small capacitors, by contrast, approach the circuit parasitic lead capacities and the input capacities of the IC inputs, producing frequencies that some remove from computed values. Thus, the lower limit of 100 pF is prudent.

Accordingly, good design choices for our example above would be: $R = 11.8K \text{ ohms}$ (MIL decade) and $C = 1 \text{ nF}$. A less optimal design choice would be: $R = 118K \text{ ohms}$ and $C = 100 \text{ pF}$.

Other Design Precautions

One of the extra NAND gates is used as an output buffer. As a general rule, always buffer oscillator outputs. The tank circuit should be the only significant load that the tank-driving output ever sees. Do not employ this circuit with a switched capacitor or resistor, since if the feedback goes open loop – even briefly – the NAND gate is so fast that the output may hang at high frequency when feedback is restored.

Connect the decoupling capacitor pair directly and closely to pin 14, V_{CC} , of the integrated circuit as shown. This will help shunt AC rail

74HC14 hex Schmitt inverter would work equally well. A subsidiary benefit of using a NAND gate is that the remaining input can be used as a strobe for the oscillator.

The design liability of feeding the output back through a capacitor – as in our “bad” example – has been avoided here. The inverter contributes 180 degrees of phase shift, and then a much safer RC low pass tank element has been used to achieve the additional 180 degrees of digital shifting.

This shift can be observed by considering that when the output changes state, the capacitor “remembers” and applies the previous output state, lagging 180 degrees, to the inverter's input. Note that output noise is now rejected by both the RC filter and the input Schmitt dead band.

Since the propagation delay for the 74HC132 is about 15 to 25 nanoseconds, we can see from our previous example in Figure 2 that this device –

+Vcc [volts]	Numerator
2.0	1.142
2.5	1.161
3.0	1.173
3.5	1.181
4.0	1.187
4.5	1.191
5.0	1.194
5.5	1.197
6.0	1.199

Tabular accuracy can vary from (-49% to +60% for $V_{CC} = 5$ volts based on the specified wide variations in the actual dead band relative to the nominal dead band.

Proteus Design Suite 7

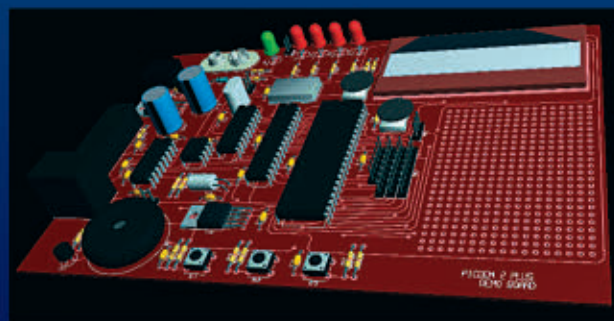
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noise – inbound or outbound – to digital ground. Keep the leads of R and C short and dressed close to the gate. Ideally, terminate C in a ground plane, rather than a trace.

Tolerances and Stability of the Oscillator

Allowing for variations in the broad Schmitt thresholds, remember, we are using digital logic as an analog component. Computer runs show a maximum unit to unit (UTU) variation in frequency from -49% to +60%, relative to Table 1. To these tolerances, we must also add component tolerances for R and C. If this is not to be a production oscillator, consider replacing R with an adjustable rheostat, and trim the frequency to the desired value. Hand trimming in production scenarios is very expensive, and if you need inherently accurate frequencies in a production setting, a quartz crystal oscillator may be more appropriate.

Duty cycle will vary between about .38 and .53, depending on the gates and Vcc. The temperature coefficient of drift will not be less than several hundred parts per million per degree Celsius.

Test Your Circuit

The First Commandment of all good design is that you can't get enough testing. Historical episodes like the disastrously under-tested Mark 14 torpedo of World War II (Ref. 2) show that a little sober, logical testing under the conditions of usage (and beyond) would have made all of the difference between success and failure, even life and death.

Test your circuit for stability and temperature coefficient beyond the range of ambient temperatures to which it will be exposed in use. Vary Vcc from six volts to two volts; go below two volts and watch the circuit's interesting decay dynamics. Cycle the power on and off at random and observe the start-up waveforms. In all cases, note the stability of frequency, amplitude, and shape of the waveforms under test variations and over time. Test the output with actual loads.

Conclusion

I would wish you good luck with your first RC relaxation oscillator design, but luck has nothing to do with it – this is engineering, and no oversight on your part will go unpunished by Mother Nature. It is important to understand what you are doing, and it is difficult to be too careful. **NV**

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(1) Datasheets for the gates shown can be obtained online at www.fairchildsemi.com. Search by part number.

(2) *Inviting Disaster*, by James R. Chiles. HarperBusiness. ISBN 0-06-662082-1. Chapter 4, "Testing is Such a Bother," pages 95 and 96.



21st CENTURY ELECTRIC GUITAR:

The Future Is Now By Edward B. Driscoll, Jr.

In his epic non-fiction *Profiles of the Future*, Arthur C. Clarke wrote that when a technology reaches the peak of its design, any changes are evolutionary, rather than revolutionary. And the electric guitar is no exception.

In hindsight, often one of the reasons is market forces as much as innovation. In the case of the electric guitar, early instruments and amplifiers played such an important role in the development of rock & roll music that most guitarists buying an electric guitar today want to buy instruments that resemble, as closely as possible, those guitars and amps used by their heroes: Eric Clapton, Jimi Hendrix, Jimmy Page, and Pete Townshend. So, radical attempts at redesigning the instrument's technology often make an initial splash, garner some press and trade show coverage, but rarely succeed long-term at being incorporated

into the musical vernacular. Which is why many guitarists spend most of their time looking in the review mirror, considering the '52 Fender Telecaster, '59 Gibson Les Paul, and '66 Marshall amplifier the height of guitar technology.

And while those are all fine instruments, constantly looking backwards can limit perspective. This is too bad, because there have been several attempts recently to drag the electric guitar — kicking and screaming — into the 21st century.

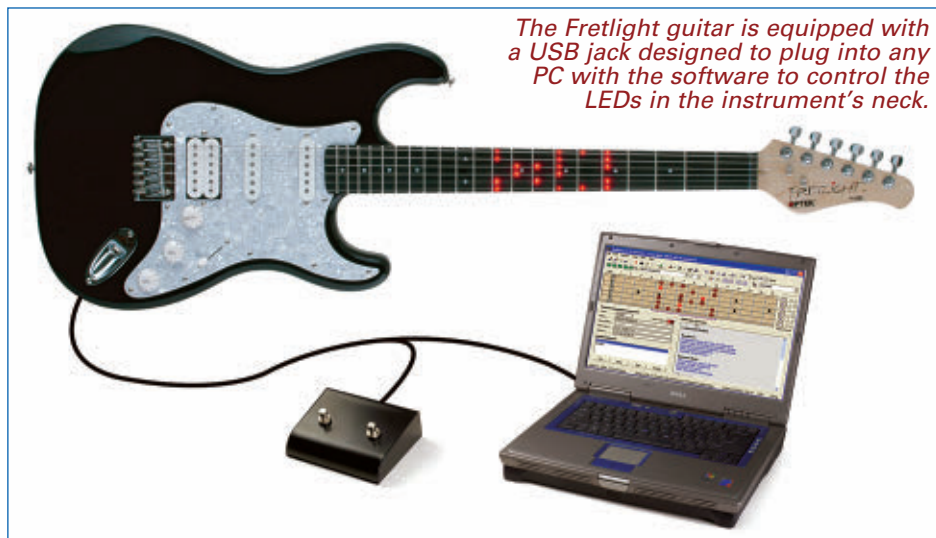
Fretlight Shines the Way for New Players

In 1982's *The Guitar Handbook*,

Ralph Denyer wrote, "The guitar is one of the easiest instruments for the beginner to learn but one of the most difficult to master."

Optek Music System's Fretlight guitar (www.fretlight.com) is designed to make learning even easier. Visually, the Fretlight is pretty astonishing: Hidden in its otherwise solid dark fretboard are 132 LEDs on a circuit board that runs the length of the neck. Via USB, they're driven by a personal computer and Fretlight's proprietary software, which allows budding guitarists to fairly easily learn where to put their fingers. Unlike the typical guitar fretboard made of rosewood or ebony, all of those lights are underneath a fretboard made of a space-age polymer. It looks like it's an ebony fretboard until the guitar is plugged into a computer via USB, and then the magic begins.

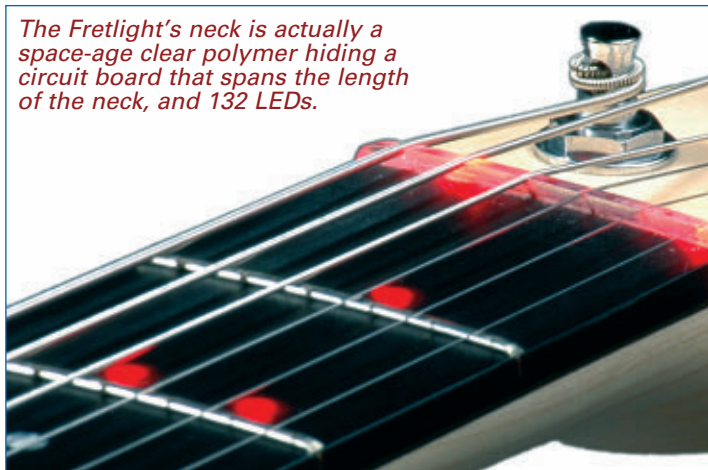
The interplay between a PC and the Fretlight guitar helps guitarists learn where to place their fingers for all sorts of scales, chords, and even complete songs. Because the software uses MIDI instead of audio recordings, the tempo of a song can be slowed to whatever speed is necessary to learn it, without the pitch of the notes being changed. So it's possible for absolute beginners to learn basic rock riffs and songs surprisingly quickly.



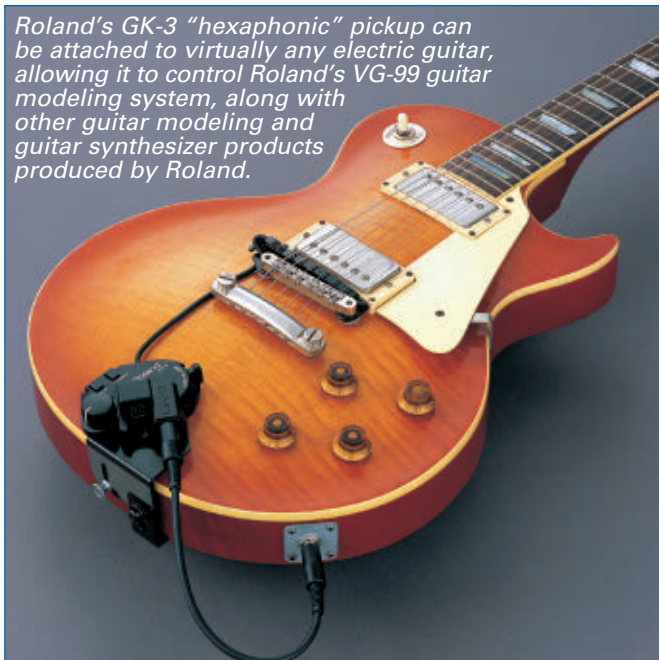
The Fretlight guitar is equipped with a USB jack designed to plug into any PC with the software to control the LEDs in the instrument's neck.

21st Century Electric Guitar

The Fretlight's neck is actually a space-age clear polymer hiding a circuit board that spans the length of the neck, and 132 LEDs.



Roland's GK-3 "hexaphonic" pickup can be attached to virtually any electric guitar, allowing it to control Roland's VG-99 guitar modeling system, along with other guitar modeling and guitar synthesizer products produced by Roland.



Rusty Shaffer, Optek's CEO and founder, invented the basic concept of Fretlight in the mid-1980s, and has been refining the technology behind it ever since. Shortly after leaving college with an undergraduate in mechanical engineering (later complemented with a law degree), he had wanted to learn to play lead guitar, but was frustrated at having to match-up guidance from instructional books with locating where all of the notes are on a guitar neck. "Somebody told me that 'You've got to learn this thing called a scale, and they showed me this book with a bunch of dots in it, essentially a scale diagram on the neck of a guitar. And I thought, 'well, this is crazy. Why doesn't somebody just take all of these dots and put them on the guitar neck under my fingers, so that while I'm learning, I could get some feedback and play?'"

And that's when the light bulb went off, so to speak. "I thought that it's got to be possible to put some kind of light system inside of a guitar," Shaffer says looking back to this period. "I never thought it couldn't be done."

The first versions of Fretlight were much more basic than the company's current model. "Remember, this was back in the late '80s, early '90s, so it didn't really dawn on me at that time to hook it up to a computer. What I wanted to do was to simply light up a scale. So the first guitars — the FG-100 and 200 versions — basically had a

circuit board with some switches and knobs on it, that was located in the back of the body of the guitar."

Those switches controlled the only options this early version provided the budding guitarist: the first switch controlled whether chords or individual notes in a scale were visible on the guitar's neck; the second switch showed the key those notes or chords were in; and the third switch would control whether they were in major or minor. "And then boom! Statically, right there, the whole neck of the guitar had this scale or chord pattern lit up to represent it," Shaffer says, looking back. And these early versions of the Fretlight used a

conventional rosewood fretboard with 132 holes drilled into it for its lights, each covered with a clear plastic cap.

Shaffer eventually refined the Fretlight over a few different iterations (including the FG-300, a version that connected to Windows 95 via the serial port, which he describes now as not for the faint-hearted computer user of the day!) during the 1990s, before arriving at its current version in 2002.

"Between 1999 and 2002 so much changed, computer-wise: the Internet, USB, and online commerce. All of these things added up to the

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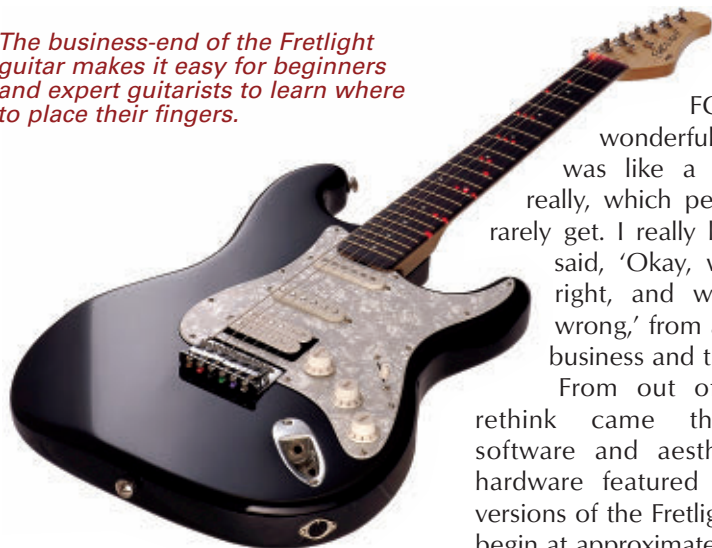
Note: To see video of the Fretlight in action, visit the Nuts & Volts Weblog: www.nutsvolts.com/blogs/index.php?/site/post/the_future_of_guitar/

MaGIC-equipped Gibson Digital Les Paul

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The business-end of the Fretlight guitar makes it easy for beginners and expert guitarists to learn where to place their fingers.



rebirth of the Fretlight with the FG-400. It was a wonderful time for me; it was like a second chance, really, which people in business rarely get. I really looked back and said, 'Okay, what did we do right, and what did we do wrong,' from all aspects of the business and the product."

From out of that industrial rethink came the user-friendly software and aesthetically-pleasing hardware featured on the current versions of the Fretlight, whose prices begin at approximately \$400.

Any Sufficiently Advanced Technology

While the Fretlight is designed to be a useful tool for guitarists learning new material, for many guitarists, the ultimate goal of learning to play is to play live. And that's the focus of another ambitious attempt to propel the guitar into the future: Gibson's MaGIC system, which stands for Media-accelerated Global Information Carrier. Gibson Guitar Corporation's goal is to create a unified audio and video wiring standard for not only electric musical instruments, but for live concerts, recording studios, and even the home theater, where Gibson boasts that its MaGIC technology could easily be used to wire up audio/video components and speakers.

MaGIC is built around the familiar RJ-45 plug that Ethernet cables use. Gibson's first product showcasing MaGIC — which has only recently begun roll-out to retailers after a long gestation period — is a Les Paul solidbody guitar dubbed the Les Paul "HD.6x-Pro," with a street price of \$4,000. It's equipped with a MaGIC jack and a "hexaphonic" pickup (so-called because it separates each of the guitar's six strings, rather than the traditional pickup, which sums them to a single output), as well as a breakout box designed to connect

the guitar to a traditional amplifier. MaGIC-equipped amplifiers are promised for the future.

But this is merely the tip of the iceberg of what Gibson has in mind. The hexaphonic pickup and breakout box give each of the guitar's six strings the ability to go to a separate amplifier and/or effects pedal. A MaGIC-equipped guitar could control a synthesizer. It could also be plugged into a concert light show, with each string triggering a different light or visual effect.

And it could also allow the electric guitar to be plugged directly into a digital audio workstation (essentially, a PC with the necessary hardware and software to digitally record music) with a proprietary Ethernet card.

Why the special card? While MaGIC uses Ethernet cables, it replaces the TCP/IP standard with its own, for reduced latency. Gibson isn't planning on entirely replacing the traditional quarter-inch jack-equipped Les Paul with the new MaGIC-equipped model. Too many purists who want to purchase recreations of the 1950s models played by Eric Clapton, Jimmy Page, Keith Richards, and Duane Allman in the 1960s and '70s would be offended.

Guitar Modeling: One Guitar, Hundreds of Sounds

While the MaGIC system can theoretically be used to connect the electric guitar to a synthesizer or a PC, a Japanese firm has a leg up in this department on Gibson. The Roland Corporation has been making synthesizers controlled by electric guitars since the early 1970s.

Such an instrument has always been a mixed blessing. Getting a keyboard to accurately trigger an electronic sound is relatively easy. Getting a guitar pickup that can accurately track a finger on a guitar string pressing against a fret underneath and accurately convert that information into the appropriate



21st Century Electric Guitar

electronic musical note has been a much more difficult proposition.

Adding to the challenge are the techniques that are unique to fretted instruments: bending strings, and slurring and sliding notes.

Roland solved many of those problems with their VG-8 guitar modeling system in the late 1990s, which they followed in the “naughts” with the VG-88, and this fall they’re replacing it with their latest model — the VG-99 — which is scheduled to street for about \$1,200.

The VG-series has long allowed a gigging guitarist to cut down on the number of guitars he needs to pile into his car’s trunk for a live date, and has opened up all sorts of avenues of sonic exploration for the guitarist in the recording studio. Unlike the original VG-units though (which could only model one instrument at a time), the VG-99 adds the option of layered multiple instruments (such as a 12-string acoustic behind a cranked Les Paul model or a classical guitar with a synthesizer pad underneath) with each instrument in its own tuning. Along with the ability to switch from open to standard tuning mid-song at the push of a button.

Flipping Through the Presets

The VG-99 requires a guitar equipped with a Roland-compatible hexaphonic pickup and 13-pin cable, such as Fender’s Roland-Ready Stratocaster model.

Inside the VG-99’s presets, expect to find all sorts of simulated amps, including replicas of Marshalls, Fenders, Voxes, Mesas, Hi-Gains, and Roland’s own JC-120. There are also a variety of modeled guitars, including Les Pauls, ES-335s, Fenders, steel and nylon-strung guitars, 12-strings, Jazz and P-Basses, and more exotic instruments such as Dobros, mandolins, and even violins. It’s also possible to model a guitar completely from scratch, even with physical parameters impossible on a real instrument.

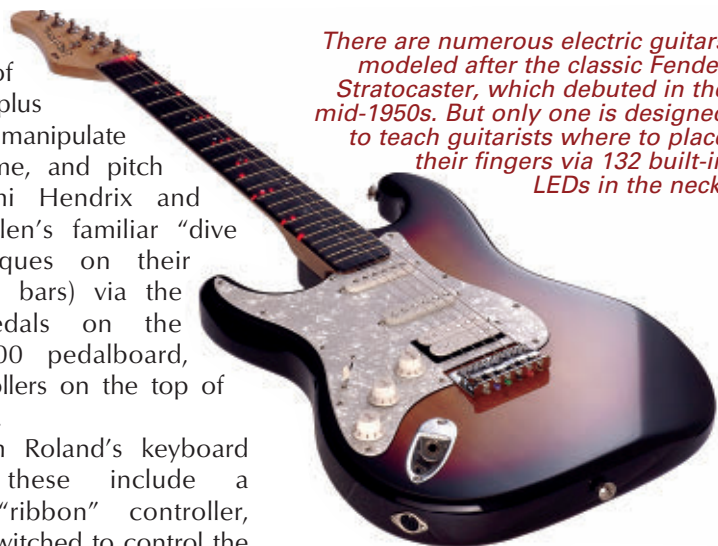
And there are all sorts of effects as well, plus the ability to manipulate wah-wah, volume, and pitch (simulating Jimi Hendrix and Eddie Van Halen’s familiar “dive bomb” techniques on their guitar’s vibrato bars) via the two foot pedals on the optional FC-300 pedalboard, and two controllers on the top of the VG-99 itself.

Taken from Roland’s keyboard synthesizers, these include a finger-sliding “ribbon” controller, which can be switched to control the pitch and filter settings of most patches. Perhaps more intriguing, there’s also Roland’s “D-Beam,” which can control many patches by waving a hand over the VG-99, or even a guitar neck. The D-Beam could provide the opportunity for some flashy stage gestures, reminiscent of Jimmy Page and his Theremin in Led Zeppelin’s *Song Remains The Same* live concert movie. And for guitarists who wish to output their Roland-ready guitars to traditional MIDI-equipped keyboard synthesizers or PC software synthesizers, there’s a built-in version of Roland GI-20 interface; a product I reviewed for the August ‘06 issue of *Nuts & Volts*.

The Conservative Guitar Slinger

Selling these kinds of innovative instruments can be a challenge for their manufacturers. While the electric guitarist has outwardly always been the wild man of rock and roll, inwardly, he’s a pretty conservative guy — at least when it comes to what he wants from an instrument. In the fast changing, kaleidoscopic world of rock music and those who wish to emulate their guitar heroes, some changes actually come very, very slowly. But for those players wishing to experiment — and wishing to enhance their music with sophisticated 21st century electronics — the future is now. **NV**

There are numerous electric guitars modeled after the classic Fender Stratocaster, which debuted in the mid-1950s. But only one is designed to teach guitarists where to place their fingers via 132 built-in LEDs in the neck.



■ BY FRED EADY

PIC32MX INTERNAL ADDRESSING

I RECENTLY SAW A SIGN THAT READ, “Everything is hard until you figure out how to do it.” As an adversary of all things complex, I grinned to myself as I passed the sign by on the highway. The PIC32MX is a prime candidate to fall into the spin of the highway sign writer’s sage observation. However, someone on the Microchip PIC32MX team saw that same sign somewhere along the way as the road that leads to the understanding and application of the PIC32MX is paved with easy to use C language macros and functions.

Just like with any other Microchip PIC microcontroller, you — the PIC programmer and PIC hardware designer — can use baseline assembler and point-to-point manual wiring techniques to bring a PIC application to life. There are instances where only an assembler application or an assembler-based function will do. In my experiences, I have found that using a good C compiler is often just as good and, more often than not, better than writing assembler code from scratch. Recently, I’ve also come to find that the microEngineering Labs PICBASIC PRO compiler can more than hold its own when compared to the code generated by a good PIC C compiler.

In the case of the PIC32MX, Microchip has provided a set of C macros and C functions that can be called from Microchip’s MPLAB C32 C compiler. These macros and functions are collections of the atomic C statements necessary to accomplish the targeted operation. For instance, to erase a page of PIC32MX program Flash, a number of individual C statements are required to initialize the PIC32MX’s NVM-related registers and unlock the targeted block of program Flash. Instead of having to look up and code all of the particular C statements necessary to perform a program Flash page erase, we can simply call on the PIC32MX Peripheral Library function `NVMErasePage`. From the programmer’s view, the set of C statements needed to perform the program Flash page erase is reduced to a single statement: `NVMErasePage((void*) 0xBD000000);`, where the hexadecimal argument is the beginning of the 4 KB program Flash page to erase.

Before we can successfully utilize the Microchip-provided set of C macros and functions in a PIC32MX application, we must understand how the PIC32MX memory space is configured and accessed. We must also be able to identify how the PIC32MX is clocking its CPU versus its bank of peripherals as there are also prefabricated PIC32MX Peripheral Library functional shortcuts that can

be used in our code to configure the PIC32MX clocking scheme. The rest of PIC32MX operations can be compared directly to the operations performed by the current eight-bit and 16-bit PIC microcontroller families. For instance, the operation of the PIC32MX timer, SPI, I²C, and UART peripherals is almost identical to that of other PIC devices that include these peripherals in their native packaging. After all, the PIC32MX is designed to extend the basic PIC concepts that you have come to know over time, not replace them.

I have studied the PIC32MX very carefully and plan to use the PIC32MX in future applications. If your mind is running in the same gutter, read on. Let’s together figure out the PIC32MX and turn what seems on the surface to be hard to something easy. Once we’ve “figured out how to do it,” we can include the PIC32MX into our future Microchip PIC Design Cycles.

PIC32MX MEMORY BASICS

Pull out your hexadecimal calculator and convert 0xFFFFFFFF to decimal. If my trusty Hewlett Packard 16C hasn’t lost its little mind, you should see 0xFFFFFFFF as 4,294,967,295 decimal. Now, convert 0xFFFFFFFF to binary and count the bits. The result is: 0b11111111111111111111111111111111. Despite the numeric base, all of the previous conversions of 0xFFFFFFFF represent a 32-bit unsigned number, which happens to be the PIC32MX virtual and physical memory map’s maximum extent. Not all of the 4 GB of PIC32MX memory area is available to the PIC32MX programmer and that makes it a bit easier for us to get our arms around the virtual and physical memory segments that are important to us as PIC32MX hardware and firmware designers.

The PIC32MX’s boot Flash, program Flash memory, data memory, configuration registers, and SFRs (Special Function Registers) reside within the 4 GB memory space at

their respective memory addresses. Note that EEPROM is not a part of the PIC32MX's memory scheme. By utilizing the PIC32MX Peripheral Library NVM (Nonvolatile Memory) calls, the PIC32MX's program Flash can be used the same way that EEPROM is used in PIC devices that support on-chip EEPROM. There's lots of PIC32MX memory to work with, which is a good thing. Functional flexibility comes as standard equipment with the massive memory space by way of memory control SFRs. By loading base values into the PIC32MX's memory SFRs, separate user program and data memory areas can also be carved out of the 4 GB memory space. We can even go as far as specifying the size of our program Flash and data RAM memory areas. The PIC32MX can be configured to execute instructions from data RAM via manipulation of the values placed within the PIC32MX memory SFRs.

A graphical representation of the PIC32MX virtual and physical memory is shown in Figure 1. If you look up the word virtual, the words "computer simulation" will most likely be injected into the definition at some point. I like to think of virtual in terms of a computer's logical view of and use of its physical resources.

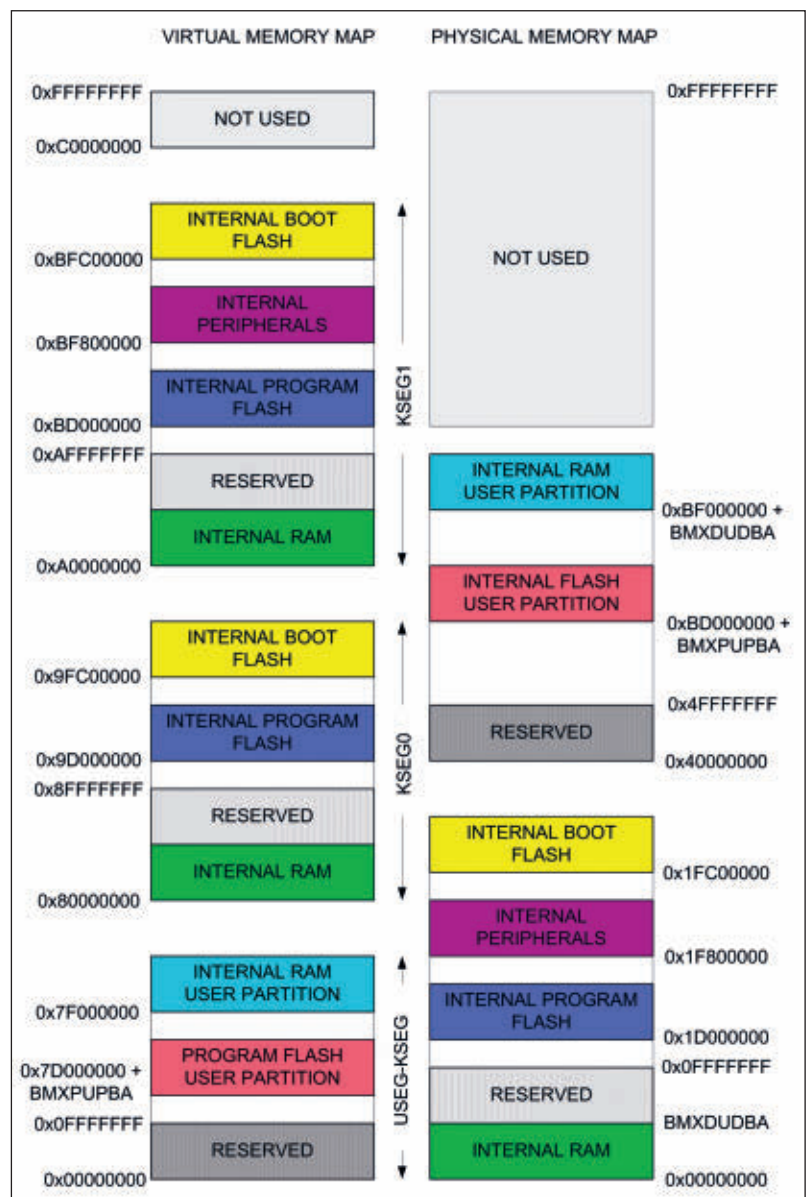
Take another look at Figure 1. The lower 2 GB (0x00000000 - 0x7F000000) of PIC32MX virtual memory space is called the USEG/KSEG segment. The "K" here represents Kernel, while the "U" stands in for User. The PIC32MX's virtual memory is divided into User and Kernel space. User mode applications must reside and execute within the USEG segment. If you're wondering why a KSEG moniker is tacked onto the USEG segment definition, that's because the USEG memory segment is also available to Kernel mode applications.

The upper 2 GB of virtual memory area (0x80000000 - 0xFFFFFFFF) is Kernel-only memory space. The PIC32MX Kernel-only memory space is partitioned into four 512 MB (0x20000000) segments: KSEG0 (0x80000000-0x9FFFFFFF); KSEG1 (0xA0000000-0xBFFFFFFF); KSEG2 (0xC0000000-0xDFFFFFFF); and KSEG3 (0xE0000000-0xFFFFFFFF). As I mentioned earlier, Kernel mode applications can dip into User mode memory space. However, User mode applications are not allowed to participate in or access the Kernel mode memory space.

Note that KSEG0 and KSEG1 are identical with the exception of the inclusion of the INTERNAL PERIPHERALS partition, which is mapped into KSEG1. The PIC32MX's CPU uses virtual addresses to address the peripherals, which means that to access the PIC32MX's peripherals we (and

the CPU) must be operating within the virtual boundaries of KSEG1. The PIC32MX's CPU also uses virtual addressing to fetch and execute program memory instructions. Here's where the virtual fetch and execution process takes advantage of its physical roots. If you look closely, you'll see that the physical address extents between the physical INTERNAL RAM at physical address 0x00000000 and the INTERNAL BOOT FLASH beginning at physical address 0x1FC00000 match up with the virtual memory schemes of KSEG0 and KSEG1. The PIC32MX CPU maps the virtual areas of KSEG0 and KSEG1 against the same physical memory area beginning at physical address 0x00000000. KSEG0 and USEG-KSEG are cacheable while KSEG1 is not cacheable. Because both the KSEG0 and KSEG1 virtual segments point to the same physical memory area, the PIC32MX CPU can execute instructions from either the KSEG0 or KSEG1 virtual memory segment, depending on the cacheable status of the application.

The PIC32MX contains a Fixed Mapping Translation



■ FIGURE 1. At first glance, this looks pretty hard. Once you associate the virtual segments with their respective physical addresses, it all comes clear and easy. I used this memory map and the MPLAB debugger memory window to gain a better understanding of how the PIC32MX uses virtual addressing.

(FMT) unit that translates memory segments into corresponding physical address memory spaces. Looking at Figure 1, it's pretty obvious that KSEG0 and KSEG1 are mapped to physical address 0x00000000. It is also easy to see that the USEG-KSEG virtual memory area is mapped to physical address 0x40000000. Although the mapping is rather obvious, the PIC32MX datasheet contains a mapping conversion discussion that explains in detail how to arithmetically convert the virtual and physical addressing scheme.

MPLAB will display both virtual and physical memory addresses in the MPLAB debugger memory window. As you work with the PIC32MX more and more, you'll automatically identify virtual addresses in the 0x80000000 or 0xA0000000 range as RAM and addresses beginning with 0xBD or 0x9D as program Flash. Practice makes perfect. So, let's write some code that uses the PIC32MX Peripheral Library NVM functionality while the PIC32MX virtual memory concepts are still fresh in your mind.

NVM 101

In this segment, we will write some very simple code to implement what Microchip calls Run-Time Self Programming (RTSP). RTSP is the process of modifying the PIC32MX's program Flash by way of a user-written program. Before we can write any code, we must first

understand what the PIC32MX Peripheral Library NVM function needs from us to carry out RTSP operations. That's pretty easy. The NVM functions need simple word, row, and page information.

Remember, the PIC32MX is a 32-bit device and a "word" here is not the normal 16 bits you're probably used to. A PIC32MX word consists of 32 bits. A PIC32MX instruction is also 32 bits wide. In the context of our 32-bit PIC32MX, PIC32MX words lead to PIC32MX rows. The PIC32MX program Flash memory array is made up of rows. A row of program Flash consists of 128 32-bit words, or 512 bytes. Program Flash rows are combined to create program Flash pages. A page of PIC32MX program Flash memory contains eight rows, which equates to 1,024 32-bit words, or 4,096 bytes. That's pretty much all you need to know to use the PIC32MX Peripheral Library's NVM functions.

The smallest erasable portion of PIC32MX program Flash is a page. However, we can apply RTSP write techniques to a word or to a row. Thus, we can program a word at a time or 128 words at a time. So, we will need an NVM function to erase a page of program Flash (NVMerasePage), an NVM function to write a single 32-bit word (NVMWriteWord), and an NVM function to write a row of 32-bit words to program Flash (NVMWriteRow). It would also be nice to have an NVM function that would allow us to move a dataset contained within AM to program Flash. Microchip delivers that functionality with the NVMProgram function.

To use the NVM functions in our code, we must include the NVM function definitions in the header area of our source code. The NVM functions are grouped in the plib.h file, which must be included in our C source code as follows:

```
#include <plib.h>
```

Our NVM demo program will be very small. So, we can safely assume that our NVM code won't spill over into the 0xBD010000 memory region. With that, let's execute our RTSP functions against the virtual address 0xBD010000, which is equivalent to physical address 0x1D010000. Please note that if you view the disassembly listing or the Code View debugger memory window from within MPLAB, you'll see that MPLAB displays the code as if it were within the 0x9D000000 memory region instead of the 0xBD00000000 virtual memory segment. The 0xA0000000 virtual RAM area is used to display RAM contents from both the MPLAB Watch and debugger memory windows. Don't let all of this confuse you. Just think virtually.

Before we write any data we are serious about to virtual address 0xBD010000, we must erase the program Flash page associated with the target

HEX DUMP 1

Address	00	04	08	0C	ASCII
1D01_0000	5354554E	444E4120	4C4F5620	00005354	NUTS AND VOLTS..
1D01_0010	00000004	00000005	00000006	00000007
1D01_0020	00000008	00000009	0000000A	0000000B
1D01_0030	0000000C	0000000D	0000000E	0000000F
1D01_0040	00000010	00000011	00000012	00000013
1D01_0050	00000014	00000015	00000016	00000017
1D01_0060	00000018	00000019	0000001A	0000001B
1D01_0070	0000001C	0000001D	0000001E	0000001F
1D01_0080	00000020	00000021	00000022	00000023	...!... "#.#...
1D01_0090	00000024	00000025	00000026	00000027	\$....%... &...'...
1D01_00A0	00000028	00000029	0000002A	0000002B	(...) *...+...
1D01_00B0	0000002C	0000002D	0000002E	0000002F	,...-... ~.../...
1D01_00C0	00000030	00000031	00000032	00000033	0...1... 2...3...
1D01_00D0	00000034	00000035	00000036	00000037	4...5... 6...7...
1D01_00E0	00000038	00000039	0000003A	0000003B	8...9... :...;
1D01_00F0	0000003C	0000003D	0000003E	0000003F	<...=... >...?...
1D01_0100	00000040	00000041	00000042	00000043	@...A... B...C...
1D01_0110	00000044	00000045	00000046	00000047	D...E... F...G...
1D01_0120	00000048	00000049	0000004A	0000004B	H...I... J...K...
1D01_0130	0000004C	0000004D	0000004E	0000004F	L...M... N...O...
1D01_0140	00000050	00000051	00000052	00000053	P...Q... R...S...
1D01_0150	00000054	00000055	00000056	00000057	T...U... V...W...
1D01_0160	00000058	00000059	0000005A	0000005B	X...Y... Z...[...
1D01_0170	0000005C	0000005D	0000005E	0000005F	\...]... ^..._...
1D01_0180	00000060	00000061	00000062	00000063	`...a... b...c...
1D01_0190	00000064	00000065	00000066	00000067	d...e... f...g...
1D01_01A0	00000068	00000069	0000006A	0000006B	h...i... j...k...
1D01_01B0	0000006C	0000006D	0000006E	0000006F	l...m... n...o...
1D01_01C0	00000070	00000071	00000072	00000073	p...q... r...s...
1D01_01D0	00000074	00000075	00000076	00000077	t...u... v...w...
1D01_01E0	00000078	00000079	0000007A	0000007B	x...y... z...{...
1D01_01F0	0000007C	0000007D	0000007E	0000007F	...}... ~...~...
1D01_0200	FFFFFFFF	FFFFFFFF	FFFFFFFF	FFFFFFFF

■ **HEX DUMP 1.** I consecutively numbered the 32-bit words in the rowbuffer array to show you how the NVMWriteRow function would lay down the data contained within the rowbuffer array.

virtual address. Let me illustrate why it is important to erase the target page before writing new data into it. The hex dump of erased program Flash at our target virtual address of 0xBD010000 was retrieved from the PIC32MX after I executed the NVMErasePage function that follows:

```
NVMErasePage((void *)0xBD010000);
Address      00      04      08      0C      ASCII
1D01_0000 FFFFFFFF FFFFFFFF FFFFFFFF FFFFFFFF ....
1D01_0010 FFFFFFFF FFFFFFFF FFFFFFFF FFFFFFFF ....
```

Remember that physical address 0x1D010000 is mapped to virtual addresses 0x9D010000 and 0xBD010000. MPLAB will list the 0x9D010000 virtual address in the Code View of its memory window. The hex dump I've shown is the Data View of the MPLAB memory window, which obviously uses the physical address range of 0x1D010000. When you run the demo code I've provided, note that the MPLAB memory window will not automatically refresh. The updated hex dump data following the NVMErasePage statement was retrieved from the PIC32MX's program Flash by clicking on the Upload Program Memory MPLAB Debugger drop-down menu after I executed the NVMErasePage call.

Now, let's write 0x00000000 to virtual program Flash location 0xBD010000 and retrieve the program Flash contents from the PIC32MX:

```
NVMWriteWord((void*) (0xBD010000), 0x00000000);
Address      00      04      08      0C      ASCII
1D01_0000 00000000 FFFFFFFF FFFFFFFF FFFFFFFF ....
1D01_0010 FFFFFFFF FFFFFFFF FFFFFFFF FFFFFFFF ....
```

If we attempt to overwrite virtual address 0xBD010000, we will be unsuccessful as the retrieved program Flash data at virtual address 0xBD010000 will be unchanged (0x00000000). To prove this, I will attempt to write 0x12345678 to the PIC32MX program Flash at virtual address 0xBD010000 and retrieve the hex dump results:

```
NVMWriteWord((void*) (0xBD010000), 0x12345678);
Address      00      04      08      0C      ASCII
1D01_0000 00000000 FFFFFFFF FFFFFFFF FFFFFFFF ....
1D01_0010 FFFFFFFF FFFFFFFF FFFFFFFF FFFFFFFF ....
```

After the write, the program Flash location is still showing a value of 0x00000000. It seems that the program Flash zeros cannot be changed to ones programmatically. To prove this, let's try writing 0x12345678 to virtual program Flash address 0xBD010004, which is still erased (0xFFFFFFFF):

```
NVMWriteWord((void*) (0xBD010004), 0x12345678);
Address      00      04      08      0C      ASCII
1D01_0000 00000000 12345678 FFFFFFFF FFFFFFFF ....
1D01_0010 FFFFFFFF FFFFFFFF FFFFFFFF FFFFFFFF ....
```

There it is. The retrieved hex dump proves that the PIC32MX's program Flash must be erased before being programmed using RTSP techniques. I've supplied the source code for this NVM example so you can try it for yourself. All you need is the PIC32MX Starter Kit hardware and the Microchip C32 C compiler to twiddle the PIC32MX's program Flash bytes.

It's rather obvious that we can combine a number of NVMWriteWord function calls to lay down a field of data in PIC32MX program Flash. Here's an example that writes the ASCII message "NUTS AND VOLTS" to a series of program Flash locations beginning at 0xBD010000:

```
NVMErasePage((void*)0xBD010000);
NVMWriteWord((void*) (0xBD010000), 0x5354554E);
NVMWriteWord((void*) (0xBD010000 + 0x04), 0x444E4120);
NVMWriteWord((void*) (0xBD010000 + 0x08), 0x4C4F5620);
NVMWriteWord((void*) (0xBD010000 + 0x0C), 0x00005354);

Address      00      04      08      0C      ASCII
1D01_0000 5354554E 444E4120 4C4F5620 00005354 NUTS AND.
1D01_0010 FFFFFFFF FFFFFFFF FFFFFFFF FFFFFFFF ....
```

If you're having problems matching up the ASCII "NUTS AND VOLTS" to the hex dump values, that's because the PIC32MX program Flash is arranged in little endian format. Try reading the 32-bit hexadecimal words right to left in byte increments. Here's the ASCII equivalent of the word at location 0xBD010000:

53 54 55 4E = S T U N

We can also put the "NUTS AND VOLTS" ASCII message into PIC32MX program Flash by using yet another NVM function called NVMWriteRow. However, our "NUTS AND VOLTS" ASCII message is only 14 bytes long and using NVMWriteRow, we will be forced to write 128 words (512 bytes) no matter what. So, let's create a 128-word rowbuffer array in RAM and initialize it numerically:

```
unsigned int rowbuffer[128];
unsigned int x;

for(x=0;x<sizeof(rowbuffer);++x)
    rowbuffer[x] = x;
```

Let's add our "NUTS AND VOLTS" ASCII message to the beginning of our rowbuffer array in hexadecimal word format:

```
// IN COMMENTS  b = ASCII space = 0x20
rowbuffer[0] = 0x5354554E; //NUTS
rowbuffer[1] = 0x444E4120; //bAND
rowbuffer[2] = 0x4C4F5620; //bVOL
rowbuffer[3] = 0x00005354; //TS
```

Then, we execute:

```
NVMErasePage((void *)0xBD010000);
NVMWriteRow((void *)0xBD010000, (void*)rowbuffer);
```

The retrieved program Flash results from calling the

Virtual	SFR Name	Hex
BF80_9130	ADC1BUF0	00000000
BF80_9140	ADC1BUFD	00000000
BF80_9150	ADC1BUFE	00000000
BF80_9160	ADC1BUFF	00000000
BF80_9800	CVRCON	00000000
BF80_A000	CM1CON	000000C3
BF80_A010	CM2CON	000000C3
BF80_A060	CMSTAT	00000000
BF80_F000	OSCCON	014B3320
BF80_F010	OSCTUN	00000000
BF80_F200	DDPCON	0000000B
BF80_F220	DEVID	30938053
BF80_F230	SYSKEY	00000000
BF80_F400	NVMCON	00000003
BF80_F410	NVMKEY	00000000
BF80_F420	NVMADDR	1D010E00
BF80_F430	NVMDATA	00005354

■ **SCREENSHOT 1.** This is a view of the MPLAB v8.00's SFR/Peripherals debug window. You can mouse-over on the SFRs to get a bit-by-bit breakdown of the contents of the SFR.

Flash by way of the pagebuffer array, which is the NVMProgram-function-required working page buffer we allocated in PIC32MX RAM.

The NVM functions we've just run through are powerful stuff. Now you know how to place constants, tables, and even code into PIC32MX program Flash directly from your code. You also have the knowledge required to store externally acquired data from the capture module and analog-to-digital converter into nonvolatile storage.

CLOCKING THE PIC32MX

Let's work our way through the PIC32MX's oscillator subsystem backwards. Screenshot 1 contains the value of the PIC32MX's OSCCON (Oscillator Control Register) SFR that is supporting our NVM demo program. The two most significant bits of the OSCCON's most significant byte are not used. That leaves three bits of PLLDIV in the middle of the byte and three bits of FRCDIV in the least significant bits of the byte. The PLLDIV bits control the divisor value of the output divider that lies behind the PIC32MX's PLL (Phase Locked Loop). In our case, PLLDIV is equal to 000 and the output of the PLL is divided by one. The Fast Internal RC Clock Divider bits are set at their default value of 001, which says that the PIC32MX's internal 8 MHz clock source's postscaler is dividing the internal 8 MHz oscillator's frequency by two. At this point, we don't know if the internal 8 MHz oscillator or an external clock source is driving our PIC32MX.

Moving to the most significant bit of the next byte to the right of the OSCCON's most significant byte tells us that "Dream Mode" is disabled. "Dream Mode" has to do with the PIC32MX DMA transfer's effect on SLEEP mode. So, we really don't care about that right now. Again, moving one bit to the right, the SOSCRDY bit is set indicating that the PIC32MX's Secondary Oscillator is running. That's nice. However, that is just additional information to us as this point. The next bit to the right is unused, which leaves us with three bits of PBDIV and three bits of PLLMULT in the least significant three bits. The PBDIV bits are set as 01, which says that the PBCLK is the SYSCLK value divided by two. The PBCLK clocks the PIC32MX peripherals. The PBCLK value determines how much the PBCLK postscaler divides the incoming SYSCLK signal. Since the internal 8 MHz oscillator and the external clock sources can drive the PBCLK postscaler,

NVMWriteRow function are shown in Hex Dump 1. As you can see, our ASCII message "NUTS AND VOLTS" is resting exactly where we wanted it to be. However, we had to write 512 bytes to put it there.

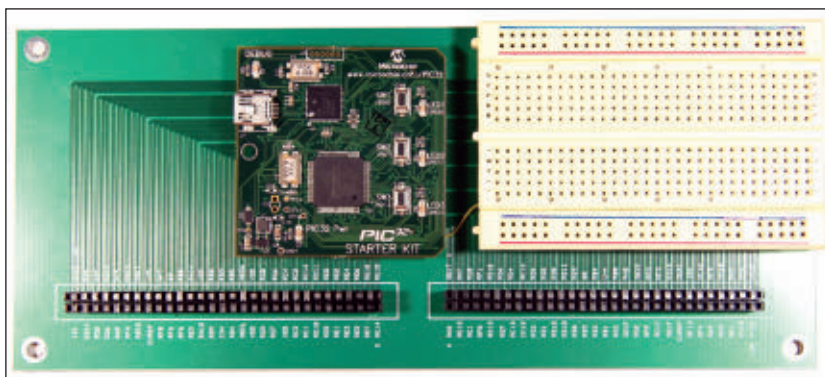
There's one more way to get the "NUTS AND VOLTS" message into the PIC32MX's program Flash. We've already initialized the rowbuffer array and placed our ASCII message at the top of the heap. So, let's define a 128-word pagebuffer array and use the NVMProgram function to write our ASCII message in the rowbuffer array into program Flash:

```
unsigned int pagebuffer[128];
unsigned int rowbuffer[128];

NVMWritePage((void *)0xBD010000,
NVMProgram((void *)0xBD010000, (const void *)row-
buffer, 16, (void*) pagebuffer);
```

Address	00	04	08	0C	ASCII
1D01_0000	5354554E	444E4120	4C4F5620	00005354	NUTS AND.
1D01_0010	FFFFFFFF	FFFFFFFF	FFFFFFFF	FFFFFFFF

Although the ASCII message is only 14 bytes in length, the NVMProgram function wants to see the amount of data being written fall on a word boundary. Thus, we had to write 16 bytes to get our 14 bytes into the PIC32MX's program Flash. Our destination program Flash address is represented as 0xBD010000. The rowbuffer array is the source of our 16 bytes of data that are destined for program



■ **PHOTO 1.** I used industrial strength VELCRO to mount the solderless breadboard. The solderless breadboard comes with a metal shielding plate, which I attached to the sticky back of the solderless breadboard. I then laced some bare wire between the shielding plate and the VELCRO sticky back. I soldered the loose end of the bare wire to ground.

■ **SCREENSHOT 2.** This waveform was generated by the PIC32MX's PWM subsystem. The PWM is running with the default clock. See if you can figure out how I came about this frequency and duty cycle by using the code clues I've provided in the download package.

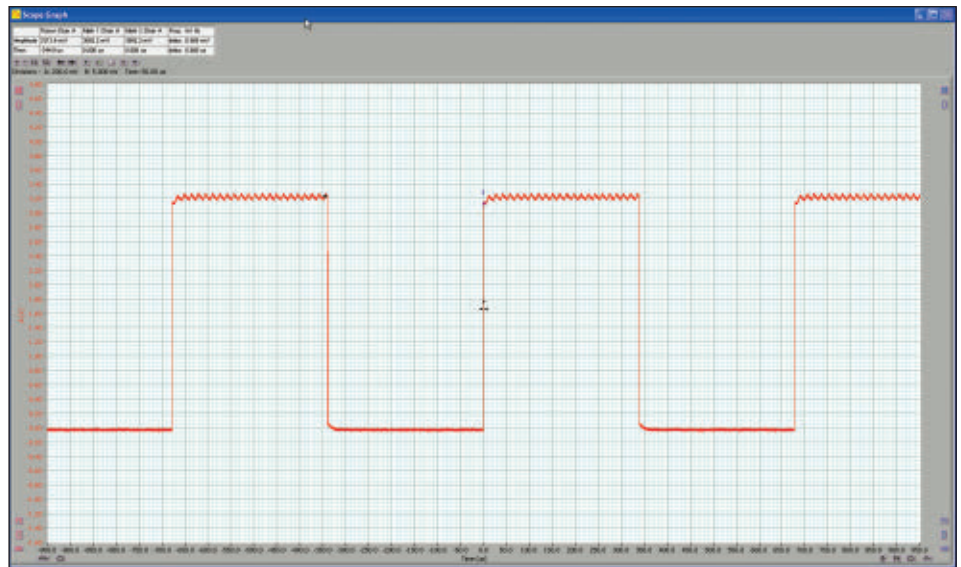
we still have no clue as to where our original clock source is originating. Maybe the PLLMUL bit value will provide a clue. Our PLLMUL value is set at 011, which tells us that the PLL clock is multiplied by 18. BINGO! We're using the primary oscillator in some fashion and it is driving the PIC32MX's PLL.

Let's move to the next byte to the right, which will tell us what type of oscillator configuration we are using. The most significant bit is unused and the next three bits to the right (COSC – Current Oscillator Selection) reveal the current oscillator that is selected. The COSC bits are arranged as 011, which translates to the Primary Oscillator with the PLL module in use. Skip the next bit to the right and we have the least significant three bits that determine which oscillator to switch over to if that is a necessary requirement. In our situation, the New Oscillator Selection bits (NOSC) are set in an identical manner to their counterparts – the COSC bits. Thus, the Primary Oscillator with PLL module is our clock source. If we parse out the remaining byte, we find that the clock and PLL selections may be modified, the PLL did indeed lock, and the Secondary Oscillator is disabled. Here's the C source code behind our PIC32MX oscillator configuration:

```
#pragma config FPLLMUL = MUL_18, FPLLIDIV = DIV_2,
FPLLODIV = DIV_1, FWDTEN = OFF
#pragma config POSCMOD = HS, FNOSC = PRIPLL,
FPBDIV = DIV_2
```

The only things we didn't get from parsing the OSCCON word were that the PIC32MX is running in an HS (High Speed) oscillator mode and that the input clock to the PLL is divided by two. The oscillator mode is set by the POSCMOD bits in the DEVCFG1 Boot Configuration Register, while the FPLLIDIV bits are found in DEVCFG2. We know from the PIC32MX Starter Kit schematic (see the PIC32MX Starter Kit information on the Microchip website) that an 8 MHz crystal is driving the PIC32MX's primary oscillator. The PIC32MX's PLL can only accept signals of 5 MHz or less, which explains why the input to the PLL (8 MHz) is divided by two. With all of that, we can now calculate the SYSCLK frequency:

```
(Primary Clock Input Frequency / FPLLIDIV) * (FPLLMUL /
FPLLODIV) = SYSCLK
(8 MHz / 2) * (18 / 1) = 72 MHz
PBCLK = SYSCLK / 2 = 36 MHz
```



SOURCES

■ **Microchip** (www.microchip.com)
PIC32MX Starter Kit; PIC32MX360F512L; MPLAB C32 C Compiler; MPLAB IDE

■ **ExpressPCB** (www.expresspcb.com)
Bare 32-Bit Expansion Board

■ **Saelig Corporation** (www.saelig.com)
CleverScope

PERFECT TIMING

I added a couple of items to our PIC32MX 32-bit Expansion Board. If you compare Photo 1 with last month's shot of the PIC32MX 32-bit Expansion Board, you'll see that I soldered in female headers and attached a solderless breadboard. These modifications allow me to wire in external components and pull out PIC32MX pin connections to the solderless breadboard.

I put my laptop-based CleverScope oscilloscope to work and captured the waveform in Screenshot 2, which was generated by the following lines of PIC32MX Peripheral Library-based code:

```
OpenTimer2(T2_ON, 0x550);
OpenOC1( OC_ON | OC_TIMER_MODE32 | OC_TIMER2_SRC |
OC_CONTINUE_PULSE | OC_LOW_HIGH , 0x550, 0x550 );
```

The functions I used to generate the square wave in Screenshot 2 are part of the PIC32MX Peripheral Library. I don't think you will have any problems figuring out what I did as what was once perceived hard is now easy to you. Congratulations! You can officially add the PIC32MX to your Design Cycle. **NV**

CONTACT THE AUTHOR

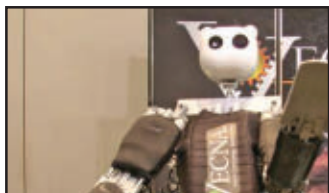
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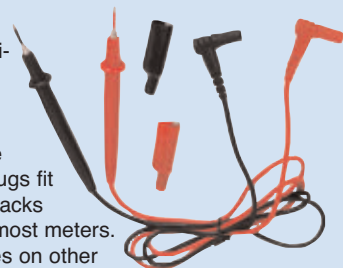
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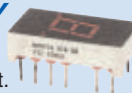
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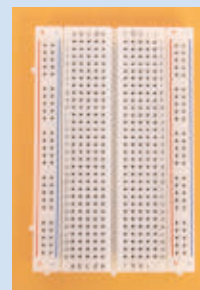
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■ BY L. PAUL VERHAGE

THE 2007 SPACEWARD GAMES

WITHIN A COUPLE OF DECADES, the United States will be reaping the benefits of a new space transportation system. It'll be a green and affordable system capable of carrying tons of cargo daily into Earth orbit and beyond. Its affordability and reliability will initiate the full exploration and exploitation of our solar system. However, to reach this future, a couple technologies must first mature. This month, we'll see how the Spaceward Foundation is helping to develop the two key technologies that will turn the Space Elevator into a reality.

The Spaceward Foundation — a non-profit corporation created in 2003 — is contracted with the NASA Centennial Challenges Office to help develop power beaming and super-strong materials technology. The Spaceward Foundation has selected an annual competition to meet this contract. Their five year contract, worth \$4 million dollars, is the prize money to two of the winners of the Spaceward Games. By offering prize money, the NASA Centennial Challenges Office is leveraging its \$4 million as teams spend their own time and money to compete in the Spaceward Games.

Each year, the Spaceward Foundation sets the competition standards higher. This incremental approach to competitions pushes the

development of the Space Elevator's two most important technologies (power beaming and super strong materials) through exciting challenges.

AT THE 2007 GAMES

My girlfriend Rachel* and I traveled to the Davis County Fair Grounds in Utah on October 19th to report on the Spaceward Games for *Nuts & Volts Magazine*. The only downside of our visit was the weather. We arrived to a wet and rainy fair ground and even saw snow that evening. Fortunately, we learned from Spaceward's media representative, Ted Semon, that Sunday's weather would be much better.

We drove to Utah to watch three competitions: the Power Beaming Competition (or Climber Competition), the Materials Competition (or Tether Pull), and the Light Racers. This month's column covers the Power Beaming competition and the next one will cover the Tether Pull and Light Racers competition. However, first, here's a brief overview of all three events.

POWER BEAMING CHALLENGE

This year, teams designed robotic climbers that had to scale a 400 foot tall ribbon at a minimum average speed of two meters per second (two m/s or 4.5 miles per hour). The climbers could not carry a power source, except for a small battery for their onboard electronics (e.g., radio receiver). This left beamed electromagnetic radiation as their sole source of climbing power. The climbers were confined to a weight range of 10 to 25 kg (22 to 55 pounds), excluding their payload. Moreover, since no team won last year's \$200,000 prize, this year the prize purse was worth \$500,000.

MATERIALS CHALLENGE

To win this year's Material's Challenge, contestants had to produce a tether 50% stronger than the house tether. This year's house tether was a two meter long, three gram heavy cable of Zylon fiber. Zylon has a breaking strength of 5.8 giga-pascals (GPa), therefore, to win, competing tethers had to be two meters long, no heavier than two grams, and have a breaking strength of at least 8.7 GPa. Since no entry beat the house tether



■ **FIGURE 1.** You can see the weather was not the best for this year's games. (I hope you brought a hair brush with you, Rachel!)

by 50% last year, the prize purse for the Materials Challenge this year was also worth \$500,000.

LIGHT RACERS CHALLENGE

Unlike the first two challenges, Spaceward's Light Racers Challenge isn't part of their NASA Centennial Challenge contract. Instead, non-NASA donors sponsored this fun challenge. To win, Light Racers had to drive down a 60 foot long track solely under beamed energy. Their energy source was the light of a high intensity spotlight. The prize purse for this year's Light Racers competition was worth \$10,000.

THE 2007 CLIMBERS

I didn't realize how serious these climber teams were until I learned their registration fee was \$5,000 — which increased to \$7,500 or even \$10,000 as competition day approached. A total of 22 teams applied for the 2007 challenge. Of them, eight completed their climbers in time for the two qualifying rounds held before we arrived. The first qualifying round took place indoors on a short ribbon suspended from the ceiling. The second qualifying round took place outdoors on a 100 foot tall ribbon suspended from a crane.

Of the eight climbers at the qualification rounds, all qualified indoors but only four qualified outdoors. We were able to visit the eight climber teams and two climber displays during our Saturday and Sunday visit. Here's what we learned from these enthusiastic teams.

KANSAS CITY SPACE PIRATES

The Kansas City Space Pirates consist of several families with the goal of lowering the cost of access to

■ **FIGURE 3.** Checking voltages is one step in prepping the Kansas City Space Pirates climber for its ribbon ascent.



SIDE NOTE

Since it's important that climbers carry a large payload at high speed, the Spaceward Foundation developed the following scoring equation.

$$\text{Score} = (\text{payload weight} \times \text{speed}) / (\text{climber weight} + \text{payload weight})$$

So for example, a 10 kg climber carrying a five kg payload at an average speed of 2.5 meters per second (m/s) would earn a score of $(5 \times 2.5) / (5 + 10)$, or 0.83.

space. Their 10 kg (22 pound) climber is square in shape and nearly 12 feet across. This was the Kansas City Space Pirate's second year at the Spaceward Games. They built their climber last year for \$50,000 and spent an additional \$35,000 upgrading it for the 2007 games. The Space Pirate's climber contains a mix of 800 dual and triple junction solar cells. To protect their fragile solar cells, the cells are mounted within balsa wood frames and suspended within the climber's airframe.

The climber travels the ribbon via two drums clamped to the ribbon and driven by an electric motor. The drums pinch the ribbon hard enough that the climber cannot slip down the ribbon. Commands to climb or descend are sent to the climber through a standard hobby remote control (R/C). To even out power fluctuations, the Space Pirates incorporated several 2.7 volt super capacitors into the climber's avionics.

Sunlight is beamed to the climber through an array of 19 mirrors. Each mirror array consists of nine closet mirrors mounted into a frame that allows team members to tip and swiv-



■ **FIGURE 2.** The Technology Tycoons climber, ready to strut its stuff.

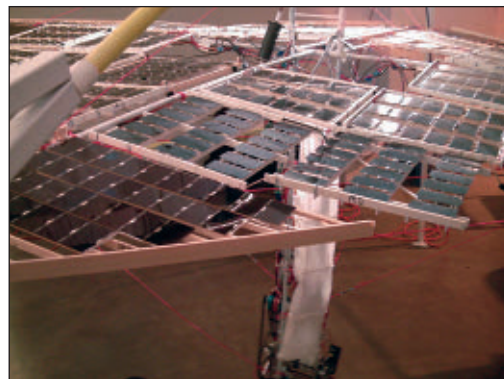
el them. Each mirror array incorporates a targeting system built from reflective tape and two pieces of glass.

Because of the spacing between the tape and glass, mirror operators see a projected red dot at their array's target. Each operator only has to keep his or her dot fixed on the climber. The combined light from the mirror array creates a beam of light at the climber 15 times more intense than natural sunlight.

TECHNOLOGY TYCOONS

Our next visit was to the Technology Tycoons of Westmont

■ **FIGURE 4.** Notice that the arrays of solar cells are mounted within balsa wood frames in this upside down view of this climber. Each frame is free to jostle to a small extent within the climber's airframe.





■ **FIGURE 5.** Looking through a Space Pirate's targeting sight shows a red dot at the mirror array's target. In competition, the mirror operator must keep this red dot centered on their climber.

High School in California. Although not affiliated with their high school, these students met every Sunday at their coach's workshop to design and build their climber. Their 12 pound climber uses two arrays of PowerFilm solar cells and measures 10 by 12 feet across. The solar cells are neat — they're amorphous and printed directly to a thick plastic cloth. This makes the solar array flexible like a thick fabric. The only drawback is that the solar array is only about 9% efficient and produces just 360 watts for their climber. To make up for the low efficiency of their array, the climber uses 90% efficient motors containing neodymium magnets. The electronics in the Technology Tycoon climber are simpler than the Kansas City Space Pirates' climber. Power from their solar array goes directly to the climber's drive motors with no voltage conditioning. As I understand it, an R/C servo on the climber mechanically

■ **FIGURE 7.** The ETC team's climber seen suspended from a ribbon. The white drum is one of two drums that pinch the ribbon and carry the climber up.



■ **FIGURE 6.** The Technology Tycoons load their climber onto the ribbon.

save money."

The solar cells in the E-T-C climber are 13% efficient and laminated between two sheets of plastic for protection. The E-T-C climber contains two arrays of six panels of solar cells. Since panels produce four amps of current at 16 volts, or 64

controls the climbing motor by pushing a power switch forwards or backwards.

The Technology Tycoons direct sunlight to their main reflector via mirrors they tilt and swivel. The main reflector — positioned at the bottom of the ribbon — then directs the sunlight straight up to the underside of their climber. The Technology Tycoon mirrors are a mix of acrylic and glass closet mirrors.

EARTH-TRACK-CONTROLLERS

The third team we visited was a combined Japanese-American team called Earth-Track Controllers (E-T-C). Members of the E-T-C team work for the company ETC, but the climber is not a project of the company. Team E-T-C spent \$30,000 and 10 months constructing their climber. However, that cost doesn't include the value of the labor that team members provided. We spoke briefly with team captain Akira Tsuchida. He said something I think everyone at the Spaceward Games would agree with. "We all want to go to space, but it's too expensive. The space elevator will

watts of power, the total power for the E-T-C climber is 768 watts. Calculations show that 768 watts of power combined with the climber's high efficiency motors will drive the 20 kg (44 pound) climber at a speed of 2.7 m/s (8.75 feet per second).

THE MCGILL TEAM

McGill was one of two microwave powered climbers at the 2007 games. Power for their climber comes from a microwave oven and is beamed through a large diameter satellite dish antenna. The climber's rectenna (or microwave receiving antenna) converts beamed microwave energy into electrical current. The microwave oven, combined with the satellite dish antenna, creates a 5 kW beam. Since the climber requires only 500 watts, there's plenty of power for the climber to reach the top of the 400 foot tall ribbon.

We learned McGill's beamed microwave system is less sensitive to pointing errors than reflected sunlight. That's because the microwave beam diverges at a greater angle (90 degrees) than reflected sunlight. Nevertheless, according to Gravenstein, microwave power is only a temporary solution. That's because next year's ribbon is too tall for their system's divergence. This year, McGill was borrowing Centaurus Aerospace's 1.2 kW magnetron and satellite dish antenna.

■ **FIGURE 8.** Alex Gravenstein explains how their climber functions.



■ **FIGURE 9.** The Centaurus Aerospace dish antenna and rectenna. Their rectenna — visible against the wall — consists of printed circuit boards and surface mounted diodes. It's very thin and flexible.

UNIVERSITY OF SASKATCHEWAN SPACE DESIGN TEAM (USST)

USST's third generation design was fantastic. Very sleek and lightweight, its power source is a laser. The USST laser transmitter is a 9 kW bank of infrared laser diodes and the receiver on their climber is an array of gallium arsenide (GaAs) solar cells. Calculations indicate that their design is capable of carrying 115 kg at a speed of 2 m/s. Team USST's 2006 entry to the Spaceward Games was the fastest, most capable design. However, it failed to win the prize purse by a mere 0.04 m/s. This year's entry weighed 25 kg, or 33 pounds.

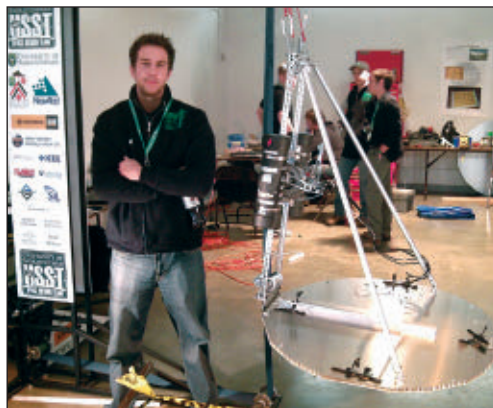
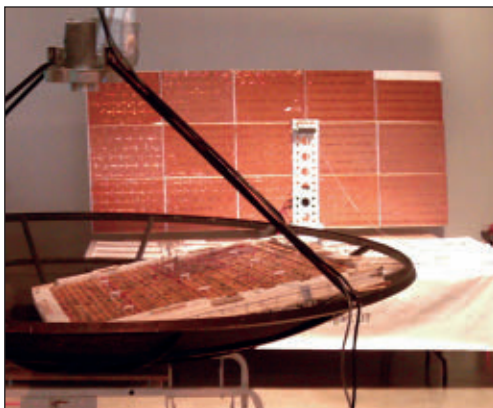
UNIVERSITY OF BRITISH COLUMBIA'S SNOWSTAR

The University of Columbia's entry, UBC Snowstar, weighed 12.5 kg because of its Kevlar, balsa, and carbon fiber kite tube construction. This was UBC's third year at the games. Unfortunately, we didn't get a chance to talk to this team before we had to leave.

ANDROMEDA CONNECTION

The last two climbers we visited were the Andromeda Connection and Team Zero-G. Andromeda Connection's climber, Sky

■ **FIGURE 11.** The University of British Columbia's entry on the ribbon. The mirror at the bottom of the ribbon directs the light from two very large mirrors to the bottom of their climber.



■ **FIGURE 10.** The University of Saskatchewan Space Development Team's laser driven climber. Because of the coherence of laser radiation, their power array is very small.

Eight climber teams arrived to the games and qualified indoors: University of Saskatchewan, LaserMotive, University of British Columbia, Kansas City Space Pirates, Technology Tycoons, Earth Track Controllers, McGill University, and Centaurus Aerospace. Two teams — Andromeda Connection and Team Zero-G — only brought displays to show and did not compete.

The second qualification round took place outdoors on a short ribbon, only 100 feet tall. The Kansas City Pirates (KCSP) entry was spectacular; it climbed the ribbon at an average speed of 3.5 m/s on Monday. Because of uncooperative weather, University of British Columbia Snowstar, Technology Tycoons, and University of Saskatchewan USST couldn't qualify until Wednesday.

As you've already read, Saturday's weather prevented climbers from running until Sunday. We briefly saw

Hopper, is substantially different in design than the other entries. Its narrow shape means that in high wind conditions, Sky Hopper won't impart a lot of lateral force or motion on the ribbon. Uniquely, its photovoltaic array is internal to the climber's body. The shape of the reflective surface inside the climber traps light shining into it, boosting the efficiency of its solar cells by 18.5%. An infrared blocking filter protects the photovoltaic array inside the climber from the heat of its concentrated sunlight (which is 40 times more intense than sunlight).

Sky Hopper's climbing motor is an 18 volt cordless drill motor operating at 24 volts. With a current draw of 110 amps, Sky Hopper is expected to climb at a speed of 2 m/s with its 95-100 pound payload.

THIS YEAR'S RESULTS

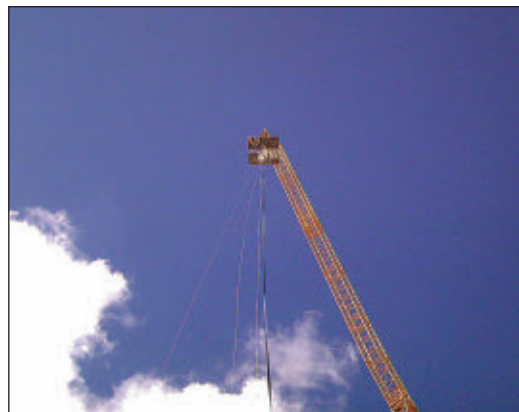
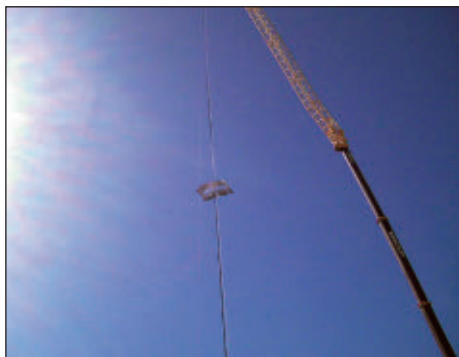
Unfortunately, due to work, we couldn't arrive early enough or stay late enough to see the entire climber competition, but thanks to information from Spaceward's Ted Semon, here's what happened.

■ **FIGURE 12.** Andromeda Connection.





■ FIGURE 13. We only had a minute to see Team Zero-G Climber. If I understand correctly, this climber will be powered by solar thermal and use a Stirling engine to drive itself up the ribbon.



■ FIGURE 14. It was a beautiful sight to see the Technology Tycoon climber at the top of the ribbon.

three climbers run on Sunday — Snowstar, Technology Tycoons, and KCSP — before leaving for home.

The Technology Tycoons made the first attempt on Sunday, too. However, their climb was not as fast as they desired (due to wind and clouds). Their coach believes it took between four and five minutes to climb to the top of the ribbon (for a speed of around 0.45 m/s).

The University of British Columbia's climber, Snowstar, made the second attempt. Snowstar climbed the 400 foot tall ribbon at a speed of nearly 1 m/s. The reason for this slower than expected speed was damage their climber received on the trip to Utah.

■ FIGURE 15. Snowstar about half way up the ribbon.

Since UBC members had midterms coming up, they couldn't wait for Monday to try again.

KCSP made Sunday's third and final attempt. Their first climb snagged one of the ribbon's safety lines and had to be brought back down. On their second attempt, the climber made it to the top of the ribbon. However, by this time, winds had picked

up. The winds whipped the ribbon and climber around and as a result, some of the solar cells broke free of the climber. The climber's beating also seized its brake, preventing it from returning to the ground as quickly as possible. Upon return to the ground, it looked bad for the KCSP climber; however, KCSP was able to make repairs and try again on Monday.

Monday began with clear skies and low winds. However, the good conditions didn't last; the winds picked up later and twice snapped the 400 foot long ribbon. Fortunately, no climbers were on the ribbon when it broke free.

KCSP made their second attempt on Monday afternoon and had a great climb. However, the climb was at a speed of 1.25 m/s and not sufficient to claim the prize money. I would guess that if their climber had not been damaged the day before, KCSP would have maintained their 3.5 m/s climb and won the \$500,000 prize.

After KCSP, it was USST from the University of Saskatchewan's turn. USST shut down their laser power system on their first attempt because of rain. Still, they managed four later trips up the ribbon in less than 40 minutes. Their average speed was 1.8 m/s or six feet per second. That was the best speed for the 2007 Spaceward Games, but still shy of the 2 m/s ascent rate needed to claim the prize purse.

Here's what Ted Semon had to say about the 2007 games. "I think the games were a success. We saw multiple laser climbs and saw a carbon nano-tube tether. These represent the technology that the Space Elevator will be built on." I couldn't agree more.



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THE 2008 SPACEWARD GAMES

There were some impressive climbs at the 2007 Spaceward Games, but none fast enough to claim the \$500,000 prize purse. Therefore, that money rolls over next year to create a prize purse worth \$1,000,000!

Of course, a prize purse that large comes with large strings attached. The 2008 games will use a ribbon 1,000 meters or 0.6 miles tall! If all goes well, the ribbon will be suspended by a large weather balloon and held in place with three cords forming a pyramid structure with the balloon at the apex. The balloon will be capable of lifting four tons and must be tied down with 1/2 inch thick Spectra cable.

As you can imagine, this structure can't just be located anywhere. Potential locations for the 2008 Spaceward Games and its ribbon structure include Meteor Crater, Arizona, Bonneville Salt Flats, Utah, and two high power rocketry sites that I have visited.

The game is slated to occur in early September 2008 and is in the

early planning stages. You don't have long to prepare if you want to field a new entry for 2008. You can read about the games and register your entries at the Spaceward Foundation website at www.spaceward.org.

Onwards and Upwards,
Your Near Space Guide **NV**

* Rachel and I were engaged on December 28, 2007.

■ **FIGURE 16.** The Kansas City Space Pirates with their climber on the ribbon.



WEBSITES OF INTEREST

Andromeda Connection
www.anconn.com

Earth-Track-Controllers
www.earth-track-controllers.com

Kansas City Space Pirates
www.kcspirates.com

McGill
<http://space-elevator.mcgill.ca>

Team Zero-G
www.teamzerog.com

Technology Tycoons
www.goingupteam.com


University of British Columbia,
Snowstar
www.snowstar.ca

University of Saskatchewan
Space Design Team
www.usst.ca.php4-3.website.testlink.com/index.php

You can read about NASA's
Centennial Challenges at their
website at <http://centennialchallenges.nasa.gov>

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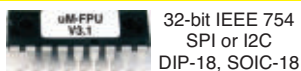
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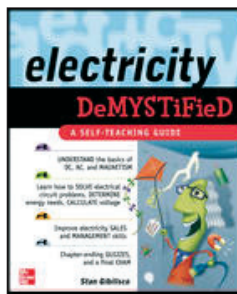
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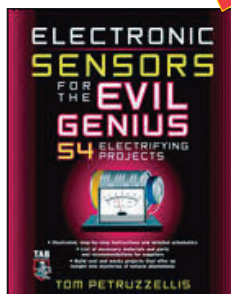


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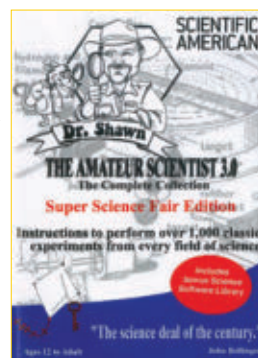
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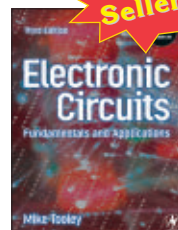
Troubleshooting and Repairing Major Appliances: 2nd Edition by Eric Kleinert

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Electronic Circuits — Fundamentals & Applications: Third Edition by Mike Tooley

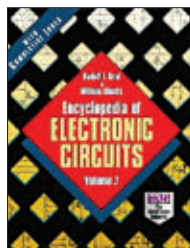
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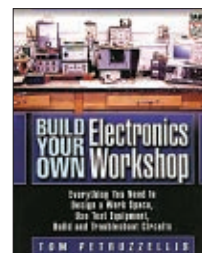


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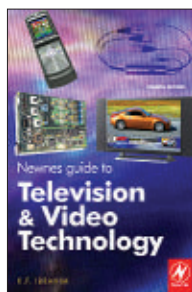
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As seen in the
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As seen in our April issue.

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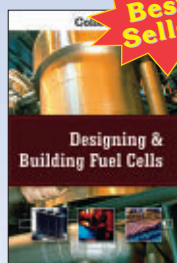


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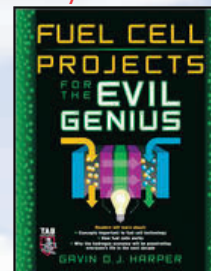
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Publish Date: October 23, 2006

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Energy Technology and Directions for the Future by John R. Fanchi

Publish Date: January 26, 2004

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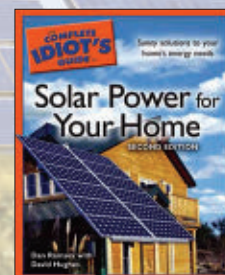


The Complete Idiot's Guide to Solar Power for Your Home

by Dan Ramsey / David Hughes

Publish Date: May 2007

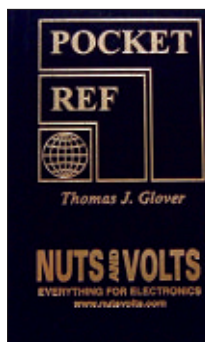
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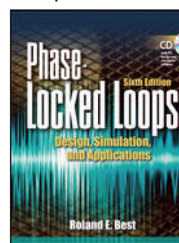


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Publish Date: July 23, 2007

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Programming HD DVD and Blu-ray Disc

by Michael Zink, Philip C Starnier, and Bill Foote

Publish Date: September 10, 2007

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■ BY JON WILLIAMS

IT'S IN THE CARDS

IT SEEMS LIKE AT LEAST ONCE A YEAR — and usually around this time of year — I remind myself (and you) that it's okay to experiment. In fact, experimenting for the sake of experimenting is absolutely worth doing and we should all make time in our schedules for experimenting that doesn't require or expect any specific results. Why? Well, we all get caught up in our dramas and the things that need to happen right this second, and oftentimes we spend more energy than required because we're not ready. This is where experimenting for the sake of experimenting comes in. My friend, Cliff, is a teacher and as an avid sports enthusiast, he frequently uses sports analogies with his students (including me). One of his favorite reminders — one that I think is wholly appropriate here — is that Michael Jordan never practiced the [specific] game (which is not possible as one cannot know what the opponent will bring to it), he practiced his skills so that he was ready for the game — and whatever an opponent showed up with.

We should do that, too, and we practice “for the game” by experimenting. I thought about this when I was recently asked if it was possible to interface a mag-stripe card reader to the SX using SX/B. “Sure, no problem!” was my enthusiastic response. “Okay, how?” The deafening silence was interrupted with my sheepish answer, “You know ... I don't know — yet — but I will find out!”

If you've read more than a few of my columns, you know that I frequently refer to myself as a very lucky guy. I'm healthy, happy, live in a great country, get to write for this very cool magazine, and I live in Los Angeles — one of the greatest cities in the world. I'm not knocking any other city, I'm just saying that Los Angeles works for me. I'm near the beach, the mountains, the desert, Hollywood Boulevard is just minutes away, and when I'm doing a project or just want to experiment ... a quick drive down the Hollywood freeway to Van Nuys gets me to All Electronics (www.all-electronics.com). Yes, electronics heaven, and it's open seven days a week! For those of you not in Los Angeles, don't worry, you can — of course — order from All via the Internet.

While on an LED shopping spree, I went looking for a mag-stripe reader because All Electronics (like Tanners and BG Micro in Texas) carries a lot of “recycled” parts. Guess what? I found a card reader and it cost me all of three bucks. So now it's time to play! I don't need the card

reader for any projects — for now — but I might later and if that comes up, or I get another request for code, I'll be ready, and there's a good chance I'll have learned something useful along the way.

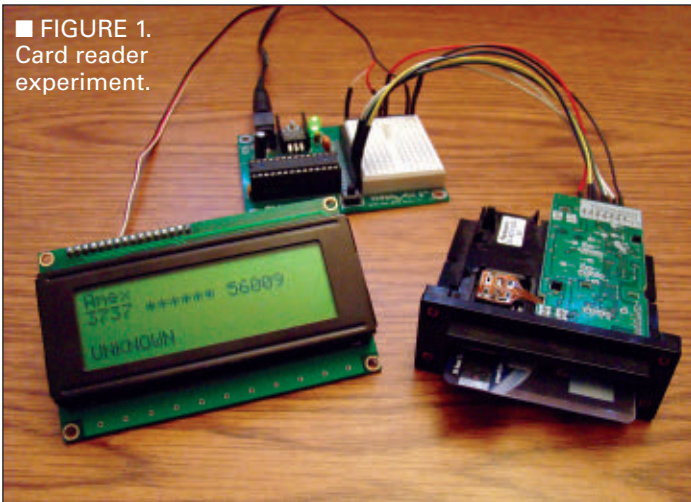
EXPERIMENTAL CONNECTIONS

The great thing about experimenting is that we don't have to worry about PCB layout and soldering unless we come up with something really cool and want to make it permanent. That said, we do have to connect things, so a little prep work is in order.

Way back in the beginnings of this column (#8), Scott Edwards taught us to build cables using female crimp pin connectors and 22-gauge standard wire. Parallax hosts online reprints of the column, so if you don't have that on your shelf you can find it at www.parallax.com/Portals/0/Downloads/docs/cols/nv/vol1/col/nv8.pdf.

Building your own cables with these connectors is a worthwhile skill, especially for prototyping and experimenting. The only thing that I'll add to Scott's excellent instructions is that for absolutely bullet-proof connections, you should use just a touch of solder on the joint. Those crimp pins were designed for machines that can exert far more pressure than we can with a hand tool, so soldering keeps the connector from breaking if the wire is tugged.

■ FIGURE 1.
Card reader
experiment.



Now ... you have to be very careful when doing this, as too much solder can cause the socket (on female connectors) to become clogged and not fit onto a pin header. The easiest way to prevent clogging is to solder these connectors the same way we would solder SMD components on a PCB: Put a drop of liquid flux on the crimped joint, put a tiny bit of solder on the tip of your iron, and then touch the iron to the crimped connection. The flux will clean everything and the solder will wick into the connection and make it permanent. The reason for the liquid flux on the joint is that applying the solder to the iron will boil off any flux in the solder. Clean the connector with a bit of 99% alcohol or flux remover and then protect it with heat shrink tubing or a box connector designed for the crimp sockets.

READ THE CARD

Figure 1 shows the setup on my desk for experimenting with the card reader. The reader has a seven-pin connector with male post headers, so I made jumper wires with a female connector on one end and a male pin on the other; the female end goes to the reader, the male end gets plugged into the SX-Tech board — a nice, low-cost setup for experimenting with the SX28.

For output, I'm using a 4x20 serial LCD. Since there are no male post headers on the SX-Tech board, I modified the LCD cable to give it male pins on one end; this lets me plug it into power and any I/O point on the SX that I desire. Figure 2 shows how I modified the standard LCD/Servo cable from Parallax to work with a solderless breadboard. Okay, we're ready to code.

■ FIGURE 2.
Modified LCD cable.

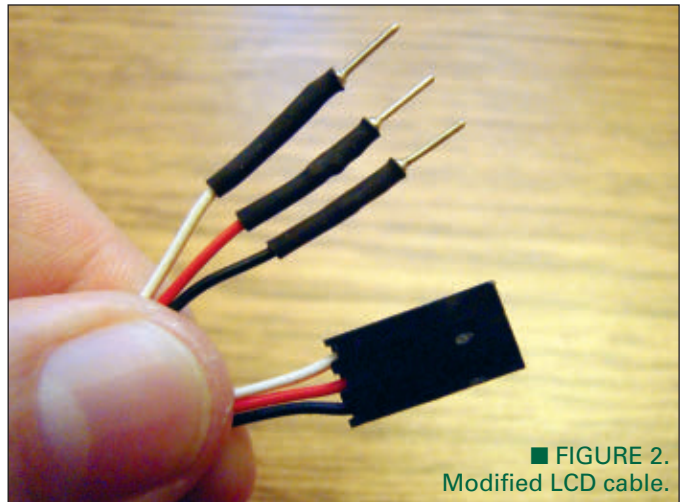
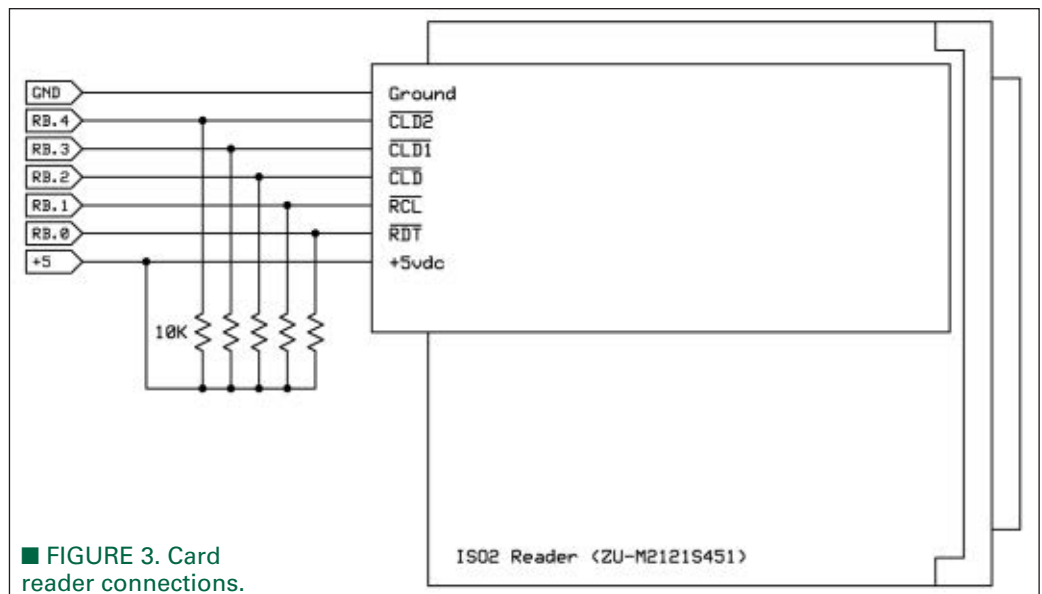


Figure 3 shows the connections between the reader and the SX. What you're probably wondering is where the pull-ups are — as they are clearly not visible in Figure 1. For the experiment, I'm using the SX's internal (weak) pull-ups. I think this is okay to do because I'm using such short connections. If we decide to install a card reader into a project where the connections are more than a foot long or so, we should use external pull-ups.

The SX/B compiler makes enabling the pull-ups on any given pin very simple — all we have to do is add the word **PULLUP** to the end of a **PIN** declaration.

CrdData	PIN	RB.0	INPUT	PULLUP
CrdClock	PIN	RB.1	INPUT	PULLUP
CrdMotion	PIN	RB.2	INPUT	PULLUP
CrdDetect	PIN	RB.3	INPUT	PULLUP
CrdEndStop	PIN	RB.4	INPUT	PULLUP

With the connections out of the way, we can look at the signals from the reader (all are active-low):



/RDT	This is the data line; will be read when a clock pulse is detected
/RCL	Clock line (this comes from the reader)
/CLD	Card is in motion; goes high if card stops
/CLD1	Card has been inserted
/CLD2	Card has hit the end stop

With this particular reader, the user is responsible for inserting the card to the stop point; the data read takes place on the insertion (not on the retraction as I originally assumed). Because there is a physical stop for the card, we are limited in how much information can be pulled from track 2, but it is enough to read the full account number cards like Visa, MasterCard, etc. Track 2 contains 40 five-bit (four bits plus parity) characters, but as we're limited by the mechanical stop we'll keep the code simple by using a 16-byte array to capture the card number — this works fine for standard credit cards.

If we break down the process for reading the card with this device, it ought to go something like this:

- 1) Prompt the user
- 2) Wait for card insertion
- 3) Look for the start sentinel character
- 4) Read card characters from track until end stop — monitor for slide error
- 5) Convert data to ASCII and display

Steps 1 and 2 are pretty easy; using a serial LCD is like using a general-purpose terminal — all we have to do is put the serial connection into an idle state and give the LCD a bit of time to handle internal initialization. Once that's done, we can clear the LCD and then display an appropriate prompt; you know, something really snappy like, "Insert Card."

```
Start:
  TX = Idle
  DELAY_MS 100

Lcd_Setup:
  TX_BYTE LcdBLOff
  TX_BYTE LcdOn1

Main:
  CLR_LCD
  TX_STR "Insert Card"
  DO UNTIL CrdDetect = HasCard
  LOOP
```

Once a card has been detected (/CLD1 goes low), we can get to the meat of the matter — reading the card number. The interesting thing about this experiment is that the reader is a synchronous serial device (i.e., it has clock and data lines), but it provides the clock instead of accepting a clock — so this precludes the use of **SHIFTIN**. Yes, we're going to have to manually code the serial input from the reader but as you'll see, it's not difficult (and this code may be useful later).

If you connect a logic analyzer to the clock and data lines, you'll see several clock pulses before any data bits

show up. This is for good reason: It allows the external device to get in sync with the clock pulses and search for what is called the start sentinel. This is a special character that precedes the card number. Let's have a look at the code that finds this start sentinel.

```
Find_Start_Sentinel:
  flags = %00000000
  char = 0
  DO
    DO WHILE CrdClock = 1
      LOOP
      char = char >> 1
      char.4 = ~CrdData
    DO WHILE CrdClock = 0
      LOOP
  LOOP UNTIL char = %01011
```

After clearing the error flags and buffer for the output, the program enters a loop that waits for the leading edge of a clock pulse. Since the data bits are provided LSB first, we prep the buffer value by shifting it to the right. Remember that a shift will cause the end bit to get a zero, so we don't have to worry about stray bits polluting the output value. Then we sample the data line, moving the inverted value to bit 4 of the buffer byte. After the clock pulse clears, we can check the value of *char* for %01011 which is the start sentinel that indicates we have alignment with the card data.

So, now you can see why the clock pulses show up first; it allows a routine line to lock onto the data stream for synchronization. Since the bits in *char* are shifted right every time through the loop, this is code acting like a sliding window on the data bits from the card. Once we detect the sentinel value, we can read the card number which — like the sentinel — is made up of five-bit values.

```
Read_Card_Number:
  FOR idx = 0 TO 15
    char = 0
    FOR bCount = 1 TO 5
      DO WHILE CrdClock = 1
        IF CrdMotion = IsStopped THEN
          slideErr = 1
          GOTO Process_Errors
        ENDIF
      LOOP
      char = char >> 1
      char.4 = ~CrdData
    DO WHILE CrdClock = 0
      LOOP
    NEXT
    buf(idx) = char
  NEXT
```

As you can see, the loop that reads the card data looks a lot like the code we used to find the sentinel; the difference, of course, is that we expect that we can read 16 packets of five bits each. When we have a character, it is moved to an array called *buf()*.

Note that in between clock pulses we do a quick check of the /CLD line which is low so long as the card is in motion. The reason for this check is to detect a partial insertion followed by a partial retraction; the card would have to stop to be retracted and as such would throw off

the synchronization of the data read. If a stop is detected, we flag the error and abort the read loop.

Once we have the data captured, we can verify it with a parity check. Since track 2 holds numbers and a few separator characters, four bits is all that is needed for the data; the fifth bit is used for [odd] parity.

```
Check_Parity:
  FOR idx = 0 TO 15
    char = buf(idx)
    bCount = 0
    FOR pCheck = 1 TO 4
      bCount = bCount + char.0
      char = char >> 1
    NEXT
    IF bCount.0 = char.0 THEN
      parityErr = 1
    ENDIF
  NEXT
```

The parity check loop pulls each byte from the buffer, counts the number of 1s in the lower four bits, and compares the result to bit 5 — if there are an odd number of 1s in the data, bit 5 should be a 0; an even number of 1s in the data means we should find a 1 in bit 5. If a parity error is detected, we'll set a flag and abort the loop.

Unless you hesitate when sliding the card or have a defective card, you probably won't see the error processing code, but it's important to include it for robust applications:

```
Process_Errors:
  IF slideErr = 1 THEN
    CLR_LCD
    TX_STR "Slide Error"
    GOTO Remove_Card
  ENDIF
  IF parityErr = 1 THEN
    CLR_LCD
    TX_STR "Read Error"
    GOTO Remove_Card
  ENDIF
```

Nothing mysterious here; we simply prompt the user and have them try again.

Okay, now that we have the data and are sure it's good, we can convert it to ASCII values to be displayed. This is really easy: We simply strip the parity bit and then add "0" (48 decimal) to convert to the appropriate ASCII codes.

```
Convert_To_Ascii:
  FOR idx = 0 TO 15
    char = buf(idx) & $0F
    buf(idx) = char + "0"
  NEXT
```

The final step is to display the card number — but let's make this a little interesting and show what kind of card was used. I found information on card type codes at <http://money.howstuffworks.com/credit-card1.htm>.

To be candid, it's not perfect because my ATM card shows up as MasterCard, and my Borders book store card reads as a Discover card. The card number is still read correctly, it's just that the algorithm used to identify the card type is somewhat simplistic.

```
Get_Card_Type:
  CLR_LCD
  char = buf(0)
  IF char = "3" THEN
    char = buf(1)
    IF char = "7" THEN
      TX_STR "Amex"
      GOTO Display_Amex
    ELSEIF char = "8" THEN
      TX_STR "Diners"
    ELSE
      TX_STR "???"
    ENDIF
  ELSEIF char = "4" THEN
    TX_STR "Visa"
  ELSEIF char = "5" THEN
    TX_STR "M/C"
  ELSEIF char = "6" THEN
    TX_STR "Discover"
  ELSE
    TX_STR "???"
  ENDIF
```

The first character of the card defines its type, and in the case of a leading "3" the second character is checked for "7" (American Express) or "8" (Diners Club). When an Amex type card is detected the card number is formatted XXXX XXXXXX XXXXX, otherwise it will be formatted XXXX XXXX XXXX.

```
Display_Standard:
  TX_BYTE CR
  FOR idx = 0 TO 3
    TX_BYTE buf(idx)
  NEXT
  TX_BYTE " "
  FOR idx = 4 TO 7
    '{ $IFDEF Secret_Display}
      TX_BYTE "*"
    '{ $ELSE}
      TX_BYTE buf(idx)
    '{ $ENDIF}
  NEXT
  TX_BYTE " "

  FOR idx = 8 TO 11
    '{ $IFDEF Secret_Display}
      TX_BYTE "*"
    '{ $ELSE}
      TX_BYTE buf(idx)
    '{ $ENDIF}
  NEXT
  TX_BYTE " "
  FOR idx = 12 TO 15
    TX_BYTE buf(idx)
  NEXT
  TX_BYTE " "
  GOTO Check_Password
```

```
Display_Amex:
  TX_BYTE CR
  FOR idx = 0 TO 3
    TX_BYTE buf(idx)
  NEXT
  TX_BYTE " "
  FOR idx = 4 TO 9
    '{ $IFDEF Secret_Display}
      TX_BYTE "*"
    '{ $ELSE}
      TX_BYTE buf(idx)
    '{ $ENDIF}
  NEXT
  TX_BYTE " "
  FOR idx = 10 TO 14
    TX_BYTE buf(idx)
  NEXT
```


► PARTS LIST

Item	Description	Supplier/Part No.
► Card Reader	ZU-M2121S451	All Electronics/MCR-12
► Dev Board	SX-Tech Tool Kit LITE	Parallax/45180
► Power Supply	12V, 1A	Parallax/750-00007
► Resonator	20 MHz	Parallax/250-02060
► LCD	4x20 Serial	Parallax/27927
► Cable	Three-pin f/f	Parallax/805-00012
► Crimp Pins	Female, 0.025	Mouser/538-16-02-0102
► Crimp Pins	Male	Mouser/538-16-02-0114
► Wire	#22, stranded	(various)

These routines work fine with a 4x20 display; if you want to use a 16 column LCD, then you'll need to remove the spaces between groups (in fact, a single loop can be used to display the card number). I have included a conditional compilation section that allows the display to be modified so that the full card number is not displayed, somewhat like what is printed on charge card receipts.

We've done it — we took a three dollar recycled ISO2 card reader and put it to use; and learned a couple neat things along the way. Before we wrap up, let's create one more bit of code. Let's say we want to compare the card number read against a known value — perhaps allowing us to use our card as an electronic ID (like my bank does when I want to do a transaction with a teller).

```

FUNC CHECK_CARD
    tmpW1 = __WPARAM12
    tmpB1 = __PARAM3
    tmpB2 = __PARAM4

    IF tmpB2 > 0 THEN
        goodCard = Yes
    ELSE
        goodCard = No
    ENDIF

    DO WHILE tmpB2 > 0
        READINC tmpW1, tmpB3
        tmpB4 = __RAM(tmpB1)
        IF tmpB4 <> tmpB3 THEN
            goodCard = No
            EXIT
        ENDIF
        INC tmpB1
        DEC tmpB2
    LOOP
    __PARAM1 = goodCard
ENDFUNC

```

This function loops through the number of characters to check, comparing a byte from the string with a byte from the card buffer. Since the card value is stored in an array, we're using the __RAM() pointer to get to it — this

will let us modify the code later to compare two cards that might be stored in different arrays.

Note the end of the code:

```
__PARAM1 = goodCard
```

We can do this because the SX/B compiler uses the __PARAMx variables to move things back and forth. We could have done this:

```
tmpB1 = goodCard
RETURN tmpB1
```

If we look at the compiled code, we'll find that tmpB1 is moved to __PARAM1 so we can just skip that and make the code a little faster.

With this function, we will pass a known good card number, either as an inline string or as a label that holds the card number as a z-string. We also need to send the pointer to the buffer that holds the card data and the number of characters we want to compare. We could, for example, use the function like this:

```

Check_Password:
    CHECK_CARD "0000000000000000", buf, 16
    TX_BYTE LcdLine4
    IF goodCard = Yes THEN
        TX_STR "JON WILLIAMS"
    ELSE
        TX_STR "UNKNOWN"
    ENDIF

```

Okay, that's it — go have some fun! It doesn't have to be with a card reader, it can be with anything. The point here is to try something new, and along the way learn something new that we can apply later. You know why Michael Jordan made so many clutch shots during his career? Because he practiced; he practiced a lot, and this made him one of the best players in the history of the game.

So go do it. Become one of the best "players" in your game. Until next time — Happy Stamping. **NV**

JON WILLIAMS
jwilliams@efx-tek.com

PARALLAX, INC.
www.parallax.com

RESOURCES
<http://money.howstuffworks.com/credit-card1.htm>

www.cyberd.co.uk/support/tech/notes/isocards.htm



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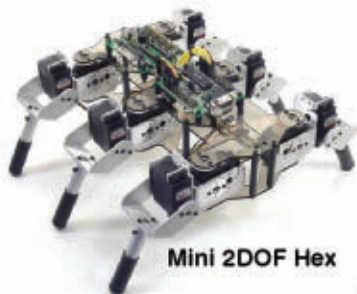
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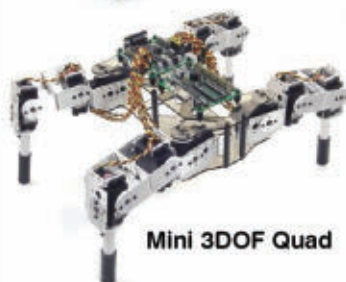
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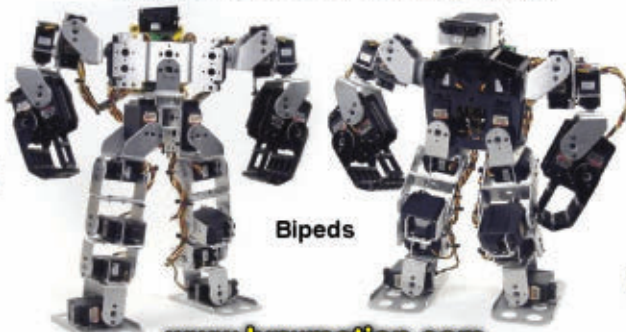
Mini 3DOF Quad



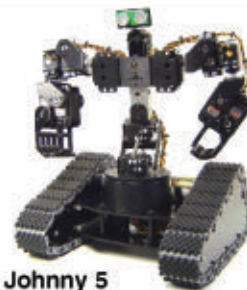
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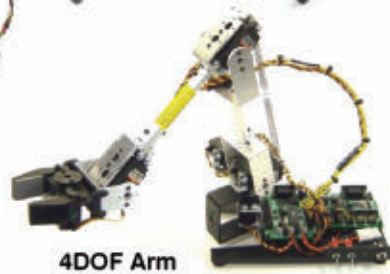
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FORUM

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All questions and answers should be sent by email to forum@nutsvolts.com All *diagrams* should be computer generated and sent with your submission as an attachment.

QUESTIONS

To be considered, all questions should relate to one or more of the following:

- ① Circuit Design
- ② Electronic Theory
- ③ Problem Solving
- ④ Other Similar Topics

■ Be brief but include all pertinent information. If no one knows what you're asking, you won't get any response (and we probably won't print it either).

■ Include your Name, Address, Phone Number, and email. Only your Name, City, and State will be published with the question, but we may need to contact you.

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ANSWERS

■ Include in the subject line of your email, the question number that appears directly below the question you are responding to.

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■ Comments regarding answers printed in this column may be printed in the Reader Feedback section if space allows.

>>> QUESTIONS

I am currently working on a windmill project that uses the dynamo of a car as the generator. Can someone suggest another way or different kind of inexpensive motor (PMDC) that will work as a generator?

Also, what charging circuit is required to charge a 12V, 40 amp battery? Any suggestions to how we can improvise our design are appreciated.

#3081

**Anthony
via email**

Can someone explain how the digital-to-analog TV converters will work?

#3082

**Charlie Eng
via email**

How can a functional, small generator with voltage regulation be built to operate on a bicycle?

#3083

**McCrary
via email**

I would like to use the sensor from a laser mouse for a rotary encoder in a robotic arm. How can I read from it, using an MCU?

My plans are to mount it inside a joint on the arm pointed at the side wall, read the distance, then translate that into rotational degrees.

#3084

**Bryan Johnston
via email**

>>> ANSWERS

[#10072 - October 2007]

I am looking for a high brightness LED with a peak wavelength around 680 nm. Is there anything similar to the offerings from Cree, Seoul, Philips, etc.?

I think that you are getting a little long in the wavelength there, almost infrared. I did find one LED which has a peak wavelength of 670 nm. According to the datasheet, it puts out about 60% power at 680 nm. Take a look at www.marktechopto.com/Products/ultra-bright-leds-features.cfm?Part_Number=MT7118-UR-A.

**Munir Mallal
Fort Collins, CO**

[#12074 - December 2007]

How do they generate that little yellow first down marker during TV football games? I know it's computer generated, but it's been driving me nuts as to how they do this!

The yellow line is "painted" into the video signal by a clever but complex system called the "1st & Ten (graphics system)" made available by Sportvision, a NY-based company who introduced it in 1998. During the game, it takes a mobile van of equipment, including seven computers and four human operators — one spotter in the press

box, one in the TV control van; and two technicians in the 1st and Ten van – who constantly adjust the system as the lighting and weather change.

TV cameras used to televise the game are fitted with encoders to collect XYZ and lens zoom settings so that the computer can modify the line to fit the playing field as seen from that vantage point. The color of the playing field is separated from the color of the player's uniforms and body so that the line is painted on the field underneath them.

Before the game, a computer model of the actual field is recorded to aid in creating the 1st and Ten graphic yellow line (which must also have the correct curve to match the playing field surface).

The broadcast TV video is passed through the 1st and Ten system to have the yellow line graphics added, and the live sound from the game (crowd and announcers, etc.) is delayed electronically to match the image processing delay caused by the graphics computers.

**Peter Stonard
Campbell, CA**

[#12075 - December 2007]

I need a device with two serial ports that can capture a line of RS-232 data at 1200 or 2400 baud and then reorder the information sequence (user definable) and resend it on demand at 1200 or 2400 baud to a PC. The purpose is to convert data from a PBX to a form the PC can recognize; the program the PC is running cannot be adjusted to read the original data. I have looked at various single board microcontrollers, but most seem to be designed for 9600 baud.

#1 Check out the offerings from Rabbit Semiconductor (www.rabbitsemi.com). They have inexpensive single-board controllers that are C-programmable and have four or more serial ports, each of which can have independent baud rates.

The BL1810 is one I am very familiar with, and it will easily do what you need.

**Robert Zusman
Scottsdale, AZ**

#2 I wish you'd specified the PBX and the program on the PC. I maintain three Nortel PBXs and half a dozen key systems, and have faced the problem of data from the switch being in an inconvenient format.

Instead of trying to correct the data between the PBX and PC with custom hardware, I captured it to file on the PC. Then the data was parsed and reformatted with a program I wrote. If the PBX is a Meridian, and if the data is LD 2 TFS (sorry about the machine specific code), I may already have what you need. If not, I may be able to help anyway.

If the program on the PC is Hyperterminal, I should warn you that Hyperterminal becomes unstable if "Capture to file" is left on indefinitely. Hyperterminal is okay, it just wasn't designed for long-term data logging. (Yes, I found out the hard way.) :-). Again, my fix was to write a terminal program that logs everything, and detects TFS and saves it to a separate file. There are too many details missing to give a more specific answer here. P.M. me at <http://forum.servomagazine.com/> username dyarker, and we can swap email addresses.

**Dale Yarker
via email**

#3 What you're looking for used to be called "RS-232 Wedge" which was software that would take a serial data stream and convert it to a keyboard sequence. The last version I used would take almost any protocol and data rate, massage the data, and transfer it to a file or a calling program. Check for "Serial keyboard software" via Google and you'll find www.keyinjector.com which sells it.

Phillip Milks

#4 From your description, it sounds like you are running a PC-based PBX. You don't state what OS is on the PC, but if it is Windows or Linux, it would be possible to write a "translator" program that would run in the background.

The program could receive your legacy phone data on one serial port and either send the translated data out on another serial port or via a virtual

serial port. The serial port you select in the PBX software could be the virtual port or a third serial port that "null modem" connects to the output port of the translation software. A PC software solution would require little additional hardware (possibly addition serial ports or USB-to-serial adapters) and easier modification; both are advantages over hardware solutions. With this solution or with a hardware solution (single board computer), you will have to develop the program to do the translation. The hardware solution would be the best bet if your PC runs a non-standard OS.

**Perry Ogletree
Murfreesboro, TN**

[#1081 - January 2008]

Anyone know a rule of thumb for determining how much energy you can pump into an LED without destroying it? I've seen many specs on maximum voltage, current, and duty cycle. However, I'm trying to determine how much current you can actually pump into one in a short duration pulse (around one microsecond) without damaging the LED junction, and at what maximum repetition rate. I've heard of strobe applications where 10X the maximum absolute current could be pulsed without destroying the LED.

#1 You are correct with the assumption that having the LED on for a short period of time allows for an increase in the intensity of the current through the LED. Basically, you want to keep the power dissipated constant. Let's assume that the manufacturers specify a value of 20 mA for continuous operation for one LED and we are going to have it ON for 0.1 seconds each second. So, this will allow for a current of 200 mA while the LED is on because it has enough time to cool off before another peak of current arrives.

Extrapolating this, we can find the maximum current as $I(\max) = I(\text{nom}) * T/\text{Ton}$ with $I(\text{nom})$ being the nominal current (20 mA) in the previous example, T is the repetition period (one second in the previous example), and Ton the time that the LED is ON (0.1 seconds in the previous example).

This equation will give a rule of

thumb for pulsed current. You need to keep in mind also that the human eye responds logarithmically to light intensity. That is, if we double the amount of light that the LED is emitting, we don't perceive it as double the light, just slightly more light.

The following websites expand on these concepts:

www.stockeryale.com/i/leds/lit/app001.htm

www.theledlight.com/technical.html
Albert Lozano
Shavertown, PA

#2 Unfortunately, there is no good rule of thumb, since the transient thermal (peak load) capability is a function of semiconductor die size, die mounting, all thermal resistances, and ambient temperature. However, it is easily measured in an application, since the junction forward bias voltage is primarily a function of temperature. Add a 1 mA constant current source to your application and look at the resulting voltage waveform with a scope and compare the lower forward voltage with the forward voltage resulting from a maximum junction temperature, which is typically $T_j=150$ deg C.

You need to heat up your assembly to the maximum junction temperature and apply your current from your constant current source and measure the voltage. This is then the forward voltage at maximum junction temperature and your constant current. The constant current adds a small amount of self-heating, which should be negligible (purists use pulsed constant current at a very low duty cycle).

You can then increase the current of your application until you reach your maximum junction operating temperature. Keep in mind that duty cycle will also play a critical role. You may want to decrease the junction temperature to a more reasonable level. The rule of thumb here is that for every 10 deg C above 100 deg C, the operating life gets halved.

For further detailed discussion, see *AN569/D Transient Thermal Resistance*, *AN1083 Basic Thermal Management of Power Semiconductors*,

AND8220/D How to use Thermal Data found in Datasheets — all from ON Semiconductor at <http://onsemi.com>. Most of them are old Motorola ANs.

Walter Heissenberger
Hancock, NH

[#1087 - January 2008]

Brushless motors are more powerful and efficient than the old brush motors but are much more sensitive to overload/overcurrent. For radio control and robot competition, I want to get as much power as possible without burning out the motor. In this application, space is limited and there is minimal air flow for cooling.

Is there a way to limit the maximum current allowed to the motor, even if stalled (a virtual short circuit), while still allowing throttle control up to that limit? The smallest motors run 10 amps continuous at 7 to 12 volts and the big ones over 40 amps at 30 to 50 volts.

#1 PWM (Pulse Width Modulation) will give you the motor control you want by dividing up the power applied to the motor into pulses. If the pulses are very narrow, the average power over time is very low, even though each pulse provides full current and full voltage. As the width of the pulses is lengthened, the average power delivered to the motor increases. You can read more about it at www.4qdttec.com/pwm-01.html

and many other websites.

Ed Schick
Harrison, NY

#2 In Figure 1, the LM339 is a quad voltage comparator and senses the current through resistors in the lower legs of the H-bridge. Higher sense voltages are more accurate but dissipate more power in the sense resistors (50 mV to 1V is commonly used). R3 and C1 suppress the capacitive start-up current spike. The outputs of both comparators form a wired OR and disable the drive circuitry for a short period of time. Supply voltage for the comparator can be adjusted over a wide range and adapt to your drive circuitry (CMOS or TTL) by changing resistance values (most brushless drives have three half bridges and motors are connected in star or delta configuration; add one comparator, the LM339 has four). You can also split up the comparators and have forward and reverse sensing if desired.

Other possibilities are Hall current sensors, some monolithic drivers have built-in capabilities, and winding resistance sensing (since resistance is a function of temperature). Wound-in RTDs (resistance temperature detectors) or PTCs are also commonly used. Thermal modeling is the current trend, but you need voltage, current, ambient temperature measurement, history, and quite a lot of CPU cycles.

Walter J Heissenberger
Hancock, NH

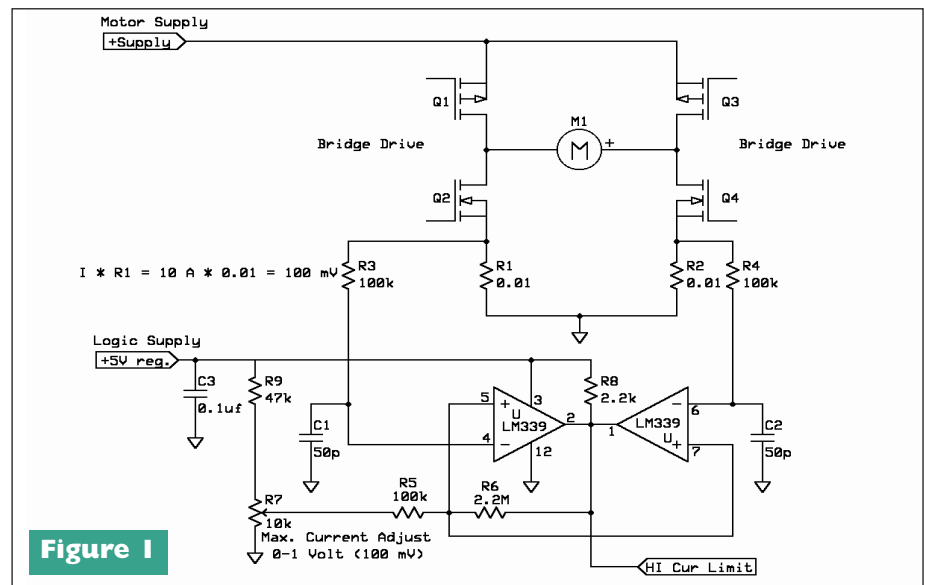


Figure 1



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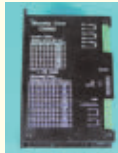
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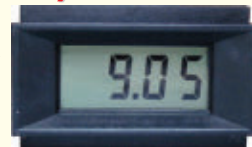
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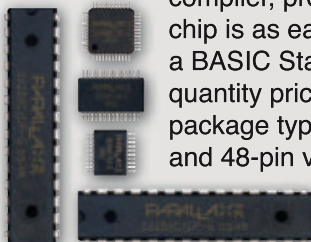
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